Agricultural and Food Research Council

ANNUAL REPORT

1991-1992

A BASIS FOR
Sustainability

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Institutes, Acronyms

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To the Chancellor of the Duchy of Lancaster

The Agricultural and Food Research Council, as required by Schedule 1 of the Science and Technology Act, 1965, submits the following report on its activities during the period from 1 April 1991 to 31 March 1992.

Sir Alistair Grant, Chairman
Professor T L Blundell FRS, Director General

Laid before Parliament pursuant to Schedule 1 of the Science and Technology Act, 1965.
19 November 1992.

MEMBERSHIP OF COUNCIL AT 31 MARCH 1992

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Sir Alistair Grant
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ICI Agrochemicals

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Unilever Research, Colworth Laboratory

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Professor T L Blundell *FRS*
Deputy Chairman and Director General

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Mr D F R George *OBE*
Dyfed Seeds

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Chief Scientific Adviser, MAFF

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Professor R M Hicks *OBE*
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Chief Scientist, Agriculture and Horticulture, MAFF

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Formerly West of Scotland College of Agriculture

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University of Oxford

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Professor W V Shaw
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CHAIRMAN'S STATEMENT

There are few years, if any, since the end of the second world war that illustrate more clearly than 1991-92 the importance of a sound scientific foundation for our agricultural and food industries. The impending completion of the Single Market will increase competition, emphasising still further the need to satisfy consumer demands and aspirations, as well as offering new market opportunities. The CAP reform agreement, by adjusting the balance between costs and income, calls for reappraisal of high-input farming systems, as does the growing integration of environmental issues into agricultural support policies. That these changes take place against a backcloth of worldwide concern about exhaustion of the planet's natural resources, exemplified by the Rio summit, and of inexorable population increase and food crises in parts of the developing world, serves only to show the complexity of the challenges we face.

A consensus about the need to develop patterns of farming and land use that are sustainable in terms of their environmental impact is matched by the recognition that these must be as sustainable in economic terms as those that met the demands of previous decades for increased efficiency of production. A strong scientific basis is essential for long term development of new technologies and to avoid simplistic or haphazard approaches. AFRC has a major role to play in providing the necessary basic information - the theme of this year's Annual Report. The Council already plays a full part in the national and international debate about future directions in agriculture and environmental sustainability. A recent example was the highly successful symposium on sustainable crop production systems and the role of emerging technologies, sponsored jointly by AFRC and the Royal Agricultural Society of England, which brought together policymakers and agriculturalists from around the world.

I am greatly encouraged by the enthusiasm with which AFRC scientists are expanding their links with researchers in other disciplines, in industry and in other countries. The bringing together of expertise in this way at the level of fundamental research is intellectually invigorating, and indicative of the healthy state of AFRC science. Particularly exciting is the synthesis of new research areas, for example, at the interfaces between biological and engineering systems, in the use of molecular data to inform ecological studies at the farmland level, and in relating food composition and structure to diet and health. The sense of scientific adventure is obvious, and I pay tribute to the commitment and dedication of AFRC's staff.

This same commitment is seen in the Council's positive response to opportunities and challenges that have arisen away from the research bench. Economic recession has added to the financial constraints and uncertainties within which the Council operates and has required prudent management of resources during this period. I particularly welcome new initiatives in industrial relations, career development and equal opportunities. Scientific excellence together with effective and imaginative research administration is a powerful mixture - and one that allows AFRC to look forward with confidence.

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Alistair Grant

Sir Alistair Grant

Chairman

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The mission of the Agricultural and Food Research Council (AFRC) is to advance fundamental and strategic knowledge for agriculture, food and other biologically based industries.

- *AFRC research is multidisciplinary with an emphasis on biological sciences, biotechnology and engineering. It provides options for the development of sustainable and diversified agriculture in an increasingly competitive and international market place.*

- *AFRC research is dedicated to the public interest and contributes to economic, social and cultural advances, to public policy and to the regulation of agriculture, food, animal health and welfare, and the environment.*

- *AFRC funds research and training in institutes, universities and other higher education institutions. Collaboration with industry enhances technology transfer.*

- *The principal source of income to AFRC is from the Science Budget of the Office of Science and Technology. The other major source of funding is from the Ministry of Agriculture, Fisheries and Food for commissioned research. AFRC also receives contract and other income from industry, Government organisations and the EC. This Report contains highlights of work supported from each of these sources.*

- *The Scottish Agricultural Research Institutes, together with the AFRC institutes, comprise the Agricultural and Food Research Service. They are funded by the Scottish Office Agriculture and Fisheries Department and are not reported on in detail in this Report.*

DIRECTOR GENERAL'S REPORT 1991-1992

For many years man has lived in equilibrium with his environment; the consumption of physical, chemical and biological resources has been small compared to the reserves available. Only recently has it become evident that this is no longer true. Science and technology have allowed man to live longer and to reproduce more effectively. Now demographic studies indicate that the human population will increase dramatically in the coming years, probably by one billion each decade until the middle of the twenty first century. The challenge will be to sustain this vast new population - a new China each decade - on a planet with limited resources. The question of sustainability is now firmly on the world agenda.

The enormity of the challenge has been obscured by the success of our manufacturing and agricultural industries in increasing production during the past fifty years. Nowhere is this more impressive than in agriculture. New breeds of crops and livestock, more effective pesticides and antibiotics, innovative mechanisation and new farming practices have all contributed to improved efficiency of the industry and increased yields of food since the war. Food now represents a much smaller percentage of domestic expenditure than at any time before and food production for developed countries is no longer a problem. Indeed surpluses in the West are often held to be evidence of our ability to sustain the growing world population, if only the logistic problems of distribution were solved and proven agricultural production systems were adopted in developing countries.

AFRC AND PARLIAMENT

During the period of this Report AFRC presented evidence to Parliamentary Committees on a wide range of issues.

Select Committee on Committee Work of the House (July 1991).

House of Commons Information Committee Inquiry on the Parliamentary Office Science and Technology (January 1992).

House of Lords Select Committee on Science and Technology: Systematic Biology Research (April 1991 - written, April 1991 - oral).

AFRC also contributed to the Royal Society Science Inquiry (June 1991 - written, July 1991 - oral).

However, the situation is certainly more complex. In western countries the diversified and labour-intensive agriculture of the early part of the century has been replaced by a system in which individual farms, and even complete regions, concentrate on one crop or livestock, and chemical and mechanised inputs are an increasing proportion of costs. Pesticide resistance is increasing and there is concern about the persistence of chemicals in the environment. These trends have been reflected in the Prince of Wales' interest in organic farming and the environmental concerns expressed in the report of the Royal Agricultural Society of England published during the year. In many parts of the world there is increasing soil erosion, deforestation and desertification, disruption of hydrogeological cycles and loss of biodiversity as a result of intensive agricultural practices and increased number of farm animals that have paralleled the increase in the human population. Important questions arise as to whether current modes of agricultural production can be sustained to provide the food for the increasing world population.

I believe that the science and engineering programmes of AFRC have much to contribute towards a solution to these problems. They provide opportunities and new technologies that can increase efficiency but at the same time conserve resources. These themes, which are as important to British agriculture as to that of developing countries, provide the basis of this year's Annual Report.

Scientific Structures

In the early days AFRC research concentrated on single commodities, components or disciplines. In the 1980s it became evident that this was an inappropriate structure, and the AFRC reorganised into eight research areas, reflected in the formation of eight institutes. This has provided for multi-disciplinary research that stresses broad areas, such as animal health and arable crops, rather than specific products and commodities.

The greatest challenge for the AFRC now is to provide further horizontal links that encourage comparative and multidisciplinary studies. This is important to molecular and cell biologists who find that genes and gene products tend to have homologues in quite different animals and plants. Research is also needed that approaches agriculture as an integrated farming practice that is part of the broader ecosystem; this requires close collaboration between animal and plant physiologists, ecologists, modellers and others interested in the agroecosystem. Thus the horizontal links must facilitate the transfer of new technologies and discoveries between research groups, whether they be in institutes or universities, and whether they be in plants, animals or food. The horizontal links should also encourage the integration of the new biotechnologies with research into agricultural systems; after all a new transgenic crop will need to be grown as part of environmentally friendly, integrated farming practice!

The AFRC has several mechanisms for increasing such horizontal links. These include the new role of Director of Science, in which Professor Brian Heap FRS has been acting. He advises on multidisciplinary areas such as genome mapping and biotechnology. The creation of the Think-Tank has also encouraged broad discussion of topics such as agricultural sustainability. In a similar way the new Strategy Board, with members drawn from universities, institutes and Central Office, has been effective at introducing more discussion of strategic issues. A further innovation is the establishment of the Engineering Board, which brings engineers of many different specialisations together with biologists and agriculturalists; this is already proving to be an effective mechanism for encouraging new engineering initiatives which have a major role to play in future AFRC research.

The coordinated programmes instituted by the AFRC have also been very effective in creating links between different institute and university groups. Thus our high priority programme on bovine spongiform encephalopathies brings together protein biochemists, geneticists, virologists and neurobiologists to tackle this mysterious and economically important disease. The coordinated programme on global environmental change links the work of plant physiologists studying stress responses, ecologists, veterinarians and environmental physicists; it also links into the sister programme of the Natural Environment Research Council.

Scientific Options

Current AFRC research includes two rather different kinds of science. On the one hand molecular biology and genetics describe individual molecules or organisms; they are reductionist in emphasis. On the other hand, nutrient management, ecology, pest control and environmental studies require more holistic approaches involving the study of integrated systems. These are usefully brought together in the concept of sustainability, which characterises much of AFRC research, and which is the theme of this Annual Report.

Most AFRC research is strategic and provides options for the agricultural, food and other biology-based industries. Such strategic research areas are selected on the basis of their relevance to our mission but the individual projects must be judged on the basis of excellence. This is true whether the science involves molecules, cells, genetics, whole animal physiology or ecosystems.

The first section of this Annual Report emphasises some of the multidisciplinary and often comparative studies carried out by the AFRC. Most examples involve horizontal transfer of techniques and understanding between our traditional institute areas and even from outside the AFRC, particularly from medicine. For example, we describe work (pp 10-11) using mobile DNA components, known as transposons, that resemble retroviruses like HIV and use similar molecular tactics to break out and then reincorporate themselves in the genome. The movements of transposons can disrupt genes that are responsible for various phenotypic traits and so tag them. This allows them to be identified and characterised. The work described here by the Birmingham and Norwich groups uses the *Antirrhinum* where the rates of transposon movement are very high. Once identified similar genes can often be located and characterised in more useful crop plants.

Another example of comparative science is illustrated in the work on cell transporters - proteins that pump molecules across cell membranes (pp 12-13). Here there are useful parallels between the molecules involved in cystic fibrosis, the transporters of cytotoxic molecules important in chemotherapy, and molecules involved in transporting antigenic peptide fragments in cellular immune responses. A further example (pp 20-21) is the use of NMR micro-imaging of water in food during cooking which exploits techniques developed for the study of a range of inorganic and biological materials.

Science for a competitive industry

The second part of the Annual Report describes research that builds on the new knowledge and new technologies; its objectives are both to sustain the efficiency and competitiveness of the industry and to sustain the natural resources, whether they be physical, chemical or biological. In general we shall need to balance these two elements or 'optimise' the whole system. Over the longer term the two become inseparable, but in this review we have separated them in order to emphasise their equal importance.

In the section of this Report that describes work designed to enhance the competitiveness of the industry we describe our studies of genomes of wheat (pp 24-25) and livestock (pp 30). These research programmes are designed to identify agronomically important genes. They will be important both to the selection of desirable traits early in traditional breeding programmes and to transgenic approaches where genes from one species can be directly characterised and transferred to another animal or plant. The possibilities for use of the new technologies are great, but they must be carefully regulated and they must be limited by what the public considers acceptable.

Diversification to non-food products

One important aspect of efficiency and sustainability of agricultural industries will be diversification into new crops including those with products other than food. In many ways agriculture has been unusual in its increased specialisation, particularly over the past three decades; in most western countries agriculture has tended towards an excessive reliance on a single crop, which often increases commercial risks, increases risk of disease, decreases biological diversity of the ecosystem and disturbs the hydrogeological system.

These are strong arguments for diversification. In fact the opportunities are great, especially for non-food uses. On page 27 we describe biological principles of short rotation willow coppicing for biomass and engineering advances in fibre extraction from cereal and other straws. Manipulation of plant genomes also offers particularly exciting opportunities for production of non-food products. On page 28 we describe how crops like rape could be genetically engineered to produce chemicals and biofuels. Such possibilities have been the subject of considerable attention both in this country and in other parts of Europe. With new scientific and technological developments, and a resource policy that favours diversification, these could become economically attractive.

It is also worth noting that animals can provide sources of new specialised products. Bayer's purchase of the new transgenic technology for producing pharmaceuticals in sheep's milk, developed at Roslin, shows that the multinational pharmaceutical industry sees such developments as a realistic proposition for the manufacture of useful drugs.

Sustaining biological resources

AFRC scientists have had research interests in the sustainability of agricultural systems for many years. The long term field studies at Rothamsted Experimental Station, which are now one hundred and fifty years old, have carefully characterised the productivity of a typical agricultural system. The development of integrated crop management systems has been pioneered in the UK through these experiments and the Less Intensive Farming and Environment (LIFE) project at Long Ashton Research Station (pp 32). These experiments are now being combined with modern computer modelling approaches that extend to the broader agroecosystem (pp 33). Engineering expertise is important to this kind of work which is now being encouraged in a new programme on farming as an engineering practice, funded as part of the joint SERC/AFRC Clean Technology Programme (pp 40).

Central to sustainability of the agroecosystem is the management of pests. Optimally pesticide use should be integrated with biological and cultural techniques to control weeds, anthropod and vertebrate pests and pathogens. There are many new biological options for crop protection and some examples are recorded in this Report (pp 35-37). They include engineering hen egg white lysozyme, an enzyme that degrades bacterial cell walls, into potatoes to protect against bacterial infections. We also describe the planned introduction into brassicas of resistance genes against fungal diseases, discovered in a model plant *Arabidopsis thaliana*. A further example is the mimicking of natural semio-chemicals, which are alarm molecules used in signalling between insects, in order to provide lures into traps for aphids.

Food: sustaining the population

The term sustainable agriculture also implies sustaining the consumer with high quality, nutritious, safe and affordable food. In this respect there needs to be better integration between the farmer, the food processor and the food retailer so that the requirements of the more discriminating consumer can influence the level and nature of investment before the farm gate. In this Annual Report (pp 51) we describe several new biological techniques that provide rapid and highly sensitive methods for estimating the quality of foods. For example, the use of enzymes to assess starch quality and immune methods to recognise gluten components that determine the quality of flour will assist the farmer in meeting requirements for high quality food.

The new science has much to offer the food industry in analysis and diagnosis of food pathogens. For rapid detection of pathogens and improved monitoring DNA technology has provided a very sensitive test capable of detecting low numbers of specific pathogens such as *Listeria* which can be linked to automated monitoring systems. The AFRC Institute of Food Research is also playing a major role in a national initiative on computer modelling of food pathogens. This will provide manufacturers with objective data from which to design for safety. The models predict the growth of food poisoning bacteria, such as *Salmonella, Listeria* and *Clostridium botulinum.* The ability to predict how bacterial growth is affected by various combinations of acidity, water content and storage temperature will enable food formulations to be designed with built-in product safety.

Our food research is increasingly concerned with diet and health. We are researching the interaction of the food with the gut (pp 46-47) and the role of diet in the prevention of diseases (pp 48-49). Traditionally AFRC has studied food until it reaches the human mouth, but no further. The new developments lead us into closer collaboration with the MRC as we approach new areas of research involving human biology. We have already appointed a clinical scientist at the Norwich Laboratory to lead some of these new developments. We are also researching consumer attitudes to food consumption (pp 50); these affect eating patterns and the health of the community.

As we study sustainable agricultural practices that will provide food for the exponentially increasing world population, so considerations of minimum dietary requirements are proving to be a major factor in defining trade and aid in human food and animal feed. It is inevitable, and indeed desirable, that the AFRC should contribute to this important debate.

People and places to work

I am delighted to report the increase of the postgraduate student stipend from October 1991. AFRC believes that the level of the postgraduate stipend is a major factor in attracting high quality graduates to a research career. Low stipends are having an adverse effect on the work carried out by PhD students, even though the paucity of job opportunities means that there is strong competition for the studentships at the present time.

We must also consider attracting students into science in general, and biology in particular, while they are still at school. AFRC has links with the National Centre for Biotechnology Education and has developed with them a programme of special schools' publications and project-based competitions. In collaboration with NCBE and the Natural History Museum a successful Schools Conference was held in May 1992 on "Biotechnology - the Way Forward".

In addition to good people we must provide good facilities. This year has seen the completion of some splendid new laboratories at Compton for the Institute for

Animal Health, and at Aberystwyth and North Wyke for the Institute of Grassland and Environmental Research. Although these new buildings have been a consequence of restructuring and have involved relocation of scientists and redundancies involving great personal distress in many cases, the new laboratories offer a very attractive environment for first class scientific research in the coming years. The sale of institute sites at Hurley, Houghton and Cold Norton that are now surplus to our requirements remains difficult in a recession, but it is an area into which we are investing considerable time and expertise.

Links with industry

AFRC has the responsibility not only for carrying out excellent strategic research, but also for facilitating the transfer of the new knowledge and expertise to industry. This has become particularly important now that Government is unwilling to fund research that has 'immediate' applications - the so-called near-market research. Much technology transfer occurs as part of collaborative research programmes funded either entirely by industry or through the Government LINK scheme.

Agriculture has provided some rather good examples of direct transfer of a technology to industry; indeed the stripper harvester, in which Silsoe has played a major role and which won the Queen's Award for Technology this year, is a good example. However, even with the stripper there is plenty of evidence for the need for close interactions between industry and the research group over a long period of time. The generation of new technology usually occurs in a series of incremental steps deriving from close and continuing discussion between industry and academia. We have endeavoured to set up the necessary structures and interactions with industry to nurture technology transfer according to this non-linear model. Thus the joint Institute of Arable Crops/ICI Agrochemicals symposia are a good example of these interactions; subjects like optimisation of crop protection methods clearly require extensive multidisciplinary discussions and collaborations with experience, knowledge and new ideas flowing from academia to industry **and** *vice versa*. Another example is our close and continuous relationship with Agricultural Genetics Company, with whom we have signed a new collaborative agreement this year.

Government funding of science

This year we have seen the transfer of the Science Vote - the funding for fundamental and strategic research - from the Department of Education and Science to the Office of Science and Technology in the Cabinet Office. AFRC welcomes this development. Strategic research is becoming increasingly generic so that new scientific discoveries become useful to a broad range of industries and Government Departments. It is, therefore, appropriate that the research is funded through a 'neutral' department. It is especially good that it is one that is close to the Prime Minister for new technology must be an essential prerequisite for most competitive industries in a country like the UK that has neither cheap labour nor abundant natural resources.

With respect to industry I am optimistic that the OST will give further support to our research underpinning biological industries in non-food areas such as fibres, pharmaceutical and fuels (see my discussion of diversification above) as well as to the agricultural and food industries. In the latter case the trade deficit in foods from temperate countries has emphasised the importance of competitive and technology-based industries to our economic well-being.

Our research is proving to be important in the formation of policy in a wide range of Government Departments. We welcome the opportunity of competing within the Government research market and have confidence in our ability to win competitive contracts. Our involvement with a wide range of industry underlines the importance of effective interactions with the DTI and the Scottish, Welsh and Northern Ireland Offices. Our links with MAFF continue to be close and strong; this is particularly important as research priorities begin to be set by policy makers who are not scientists. We have also increased our interactions with the Department of the Environment; solutions to environmental challenges must take into account the fact that more than 80% of UK land is involved in agriculture. Finally we have much to contribute to the ODA. The fact that different plants and animals have similar genes, and therefore similar structures and functions at the level of molecules, cells, tissues and whole organisms, means that new discoveries such as genes for disease resistance can be quite quickly transferred between UK and tropical crops. Our work on optimising systems to provide a sustainable agriculture is becoming increasingly important to those in developing countries, as became evident in the RASE/AFRC symposium "Towards Sustainable Crop Production Systems" held in Cambridge this summer. AFRC research generated enormous interest amongst the delegates from more than forty different countries. The AFRC is now carrying out a major appraisal of its present and potential contributions to research in and for developing countries. I foresee strong arguments for closer collaborative links with the ODA and with NRI, in particular.

It is always a pleasure to record the national and international recognition of our science, and the achievements of individual members of staff (see page 62). Also this year I am delighted to record AFRC's congratulations to Council Members recognised in the Honours Lists and in particular to our Chairman, Sir Alistair Grant on the award of Knight Bachelor in the New Years Honours 1992.

Tom Blundell

Tom Blundell FRS

Director General

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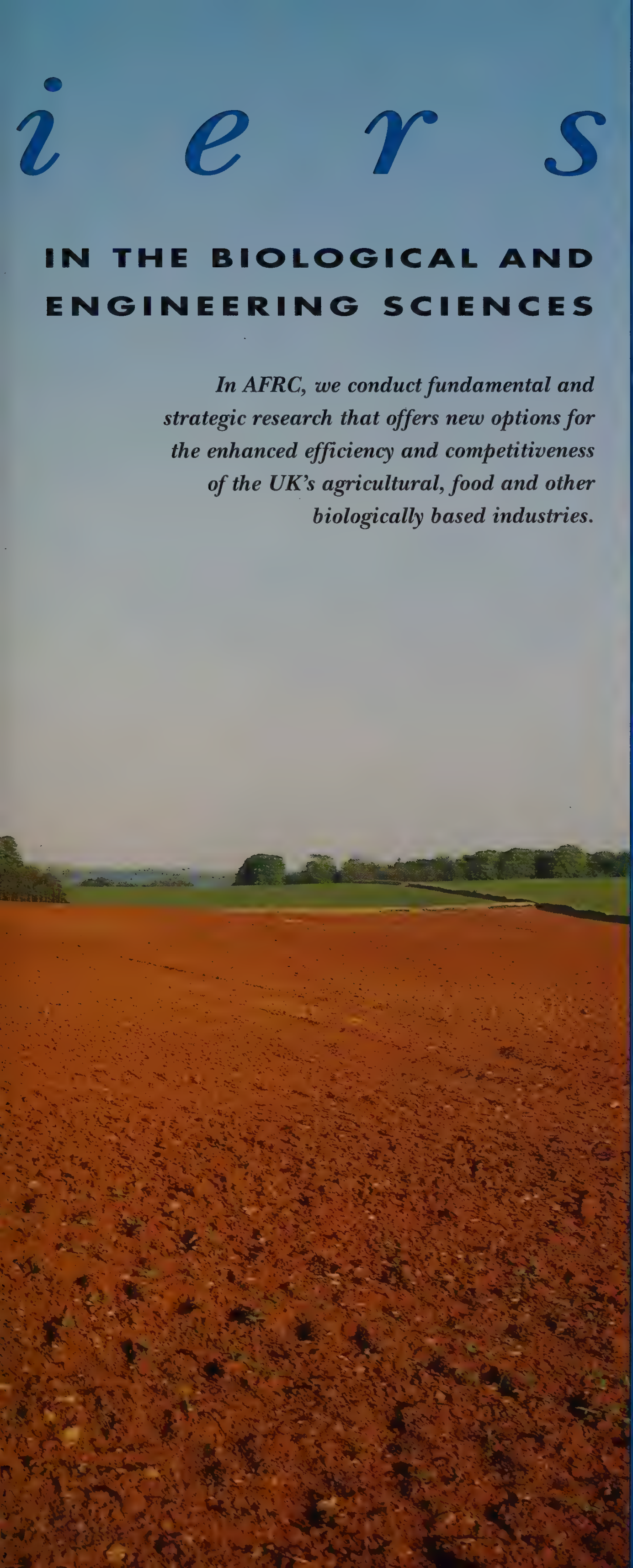
IN THE BIOLOGICAL AND ENGINEERING SCIENCES

In AFRC, we conduct fundamental and strategic research that offers new options for the enhanced efficiency and competitiveness of the UK's agricultural, food and other biologically based industries.



- *For the first time we have a method of examining a gene that codes for disease resistance in plants. Characterisation of this gene and its product should suggest new strategies for crop protection.*
- *We have made significant progress in understanding the role of transporter proteins in regulating the flow of ions and molecules across biological membranes. Two important systems are being elucidated that have implications for improving chemotherapy, and for aiding vaccine design and combating auto-immune diseases.*
- *Fundamental research on the mechanisms of windload generation on farm buildings - from full-scale studies to computer modelling - is contributing to EC design standards that will ensure fair industrial competition and protect the customer.*
- *We are characterising the genes that govern starch biosynthesis. A better understanding of the genetic control of starch composition and structure and how these characteristics determine functional behaviour, including digestibility, is paving the way for rational design of novel starches tailored for specific industrial applications.*
- *By identifying features of respiratory syncytial virus that elicit a protective immune response, we have developed a monoclonal antibody treatment that prevents and clears infection in calves. In collaboration with Scotgen, an active "humanised" monoclonal against this virus has been developed, offering a new strategy for managing this disease in young children.*
- *Knowledge of the distribution and transport of water and solutes in foods is important in controlling food safety and quality. We are using the methods of nuclear magnetic resonance to explore the transport of small molecules in food and plant materials.*
- *Studies on the molecular biology of the foot-and-mouth disease virus have provided valuable clues about how the virus can commandeer ribosomes to synthesise its own proteins while blocking production of the host cell's protein. The key lies in the different mechanisms by which the viral and host cell messenger molecules (mRNAs) are recognised by the ribosomes.*

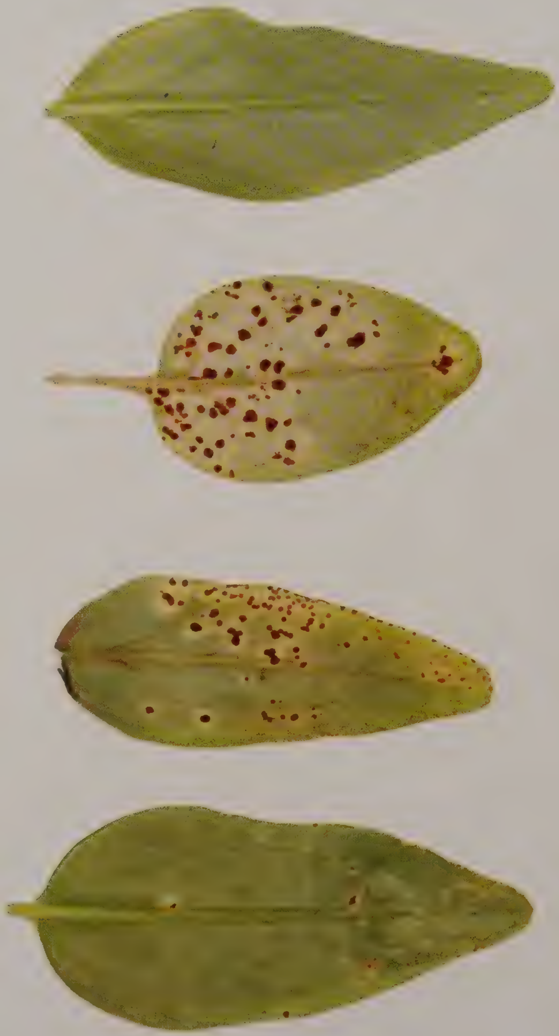
TAGGING THE GENES THAT PROTECT PLANTS FROM DISEASE

A plant's ability to defend itself against attack by a particular species of fungus or bacterium can depend on whether or not it carries a single gene - the resistance (R) gene that protects uniquely against the particular pathogen. Not surprisingly, incorporation of R genes into crop species has received much attention from plant breeders. Biologists, too, are fascinated by these genes because of the high degree of molecular recognition they exhibit. Each R gene is responsible for defence against just one "race" of pathogen; protection against other races, for example, requires different genes.

But despite their fundamental interest and strategic importance for improving methods of crop protection, R genes have so far eluded characterisation. We do not know anything about the nature of their gene products, nor where in the cell or by what mechanisms, these products confer protection.

Research groups around the world are striving to isolate R genes and characterise their protein products. One approach, adopted by AFRC-supported researchers at the University of Birmingham and at the Sainsbury Laboratory, is to "tag" the genes with mobile pieces of DNA called transposons. These are naturally occurring pieces of DNA that have evolved the ability to move from one position to another in the chromosome. They are useful tools for geneticists because when a transposon inserts into a chromosome it disrupts the normal function of the gene at that site. So by mapping how the disruptive presence of transposons at different chromosomal locations induces altered behaviour and properties of an organism, it is possible to deduce the role of genes at the different sites. Moreover, when the nucleotide sequence of the transposon is known, a molecular "hook" can be employed to pull-out the transposon together with the gene into which it has inserted. The gene may then be cloned and characterised.

Several strategies are employed to increase the chances of obtaining transposon disruptions in the target genes - in this case



The underside of Antirrhinum leaves showing different interactions with rust fungus: top to bottom: resistant, normal susceptible, and two classes of mutants which have lost their resistance because of insertion of a DNA element in the gene responsible.

the R genes. These include the use of selected experimental lines of maize and *Antirrhinum* that exhibit vastly greater rates of transposon movement than those normally encountered. Another ploy is to use lower temperatures at which some transposons show enhanced mobility.

An R gene in Antirrhinum

Researchers in Birmingham have used *Antirrhinum* transposons to look for R genes in this species. The first step was to identify disease resistance associated with a single gene. Tests with a large number of isolates of the rust fungus *Puccinia antirrhini* revealed two races of this pathogen, α and β. All lines of *Antirrhinum* tested are susceptible to the β race, some lines are resistant to the α race, i.e. some lines carry an R gene against the α race. By producing plants that carry this R gene and which also have a high level of transposon activity, the Birmingham group were ready to look for transposon insertion mutants in which R gene activity was disrupted, making the plants susceptible to attack by the α race of fungus.

After screening tens of thousands of plants such mutants have now been found. For the first time we have a molecular handle on a gene that codes for disease resistance in plants. As yet it is not certain which of the nine known transposons in *Antirrhinum* has inserted into the R gene in these mutants, the work is further complicated by the existence of multiple copies of each of the transposon types. But work has commenced to identify the transposon and extract it together with the R gene.

Information about this gene should help researchers to find comparable genes in other species, and might suggest novel strategies for combating disease - for example by mimicking properties of the R gene product.

A 19th Century illustration of how genes governing pigmentation may be disrupted by mobile pieces of DNA.

From: Histoire Naturelle Agricole et Economique du Mais *published in Paris in 1836. Courtesy of the John Innes Foundation.*

Unfortunately, active transposons have not been identified in most plant species, including those like tomato, which have been well studied genetically and in which identification of R genes and their mechanisms would be economically important. But a highly active transposon (known as Activator or Ac) from maize has been shown to be effective in other species.

Transposons in transgenic plants

Researchers at the Sainsbury Laboratory have successfully transferred Ac into tomatoes and are using it to isolate four different genes that confer resistance to the leaf mould fungus, *Cladosporium fulvum.*

In this case genome mapping techniques have been used to map the chromosomal location of these R genes. Attempts are being made to insert the Ac transposon near these regions because there is evidence from maize that Ac does not generally move very far along chromosomes. Research aimed at mapping R genes in *Arabidopsis* is described on page 35.

TRANSPOSON TAGGING OF OTHER USEFUL PLANT GENES

R genes are not the only targets for transposon tagging. The technique is now being used in a wide range of plant species to isolate genes involved in developmental and metabolic processes. For example, at the University of Dundee, the search is on for naturally occurring transposons in potato plants. At the John Innes Centre, work is in progress to isolate genes associated with the initiation and development of flowering, and the synthesis and detection of hormonal signals. This includes an EC coordinated programme using the Ac transposon to isolate genes from Arabidopsis. *At the University of Nottingham, the Ac transposon is being used in tomatoes to identify genes involved in synthesis of the plant hormone abscisic acid (ABA). As well as improving our understanding of how plants respond to water deprivation, a knowledge of the ABA biosynthetic gene could in the long-term suggest strategies for developing drought-resistant varieties.*

NEW INSIGHTS FOR IMPROVING CHEMOTHERAPY AND FOR UNDERSTANDING CELLULAR IMMUNE RESPONSES

The biological membranes that keep metabolic processes separate, within compartments of a cell or between cells, are not static barriers. They contain transporter and "channel" molecules that allow nutrients to enter, for example, and proteins and other materials to be exported. These molecules are very important in many biological processes. For example, substitution of one particular amino acid of the cystic fibrosis transmembrane regulator (CFTR) protein is associated with cell secretory failure in that disease.

Two groups at the AFRC Institute of Animal Physiology and Genetics Research - one working on chloride ion transport in cells lining the gut, and the other on the molecular basis of immunity - have made important discoveries about two proteins that resemble CFTR. One protein is notorious in medicine because it pumps chemotherapeutic drugs out of tumour cells. The second is part of the process by which cells recognise "foreign" material. Like CFTR, both belong to a family of ATP-binding cassette (ABC) proteins, of which over fifty examples have been identified in animal and bacterial cells. Scientists at the AFRC Institute of Arable Crops Research have identified a plant protein that is a member of this family.

Transporter and channel protein

Scientists at the Imperial Cancer Research Fund Laboratories at the Institute of Molecular Medicine, Oxford are interested in P-glycoprotein - a transporter that pumps cytotoxic drugs out of tumour cells, making them resistant to chemotherapy. Its similarity to the CFTR protein, which is known to be associated with a chloride channel, led to a collaboration with IAPGR to see if P-glycoprotein showed a similar association. The results are surprising: P-glycoprotein itself behaves like a chloride channel, but one different from that associated with CFTR.

This finding might offer new strategies for increasing the potency of chemotherapeutic drugs. It also raises important questions about how the function of such molecules is determined by their structure, and how they are regulated to behave either as transporters or channels but not both simultaneously.

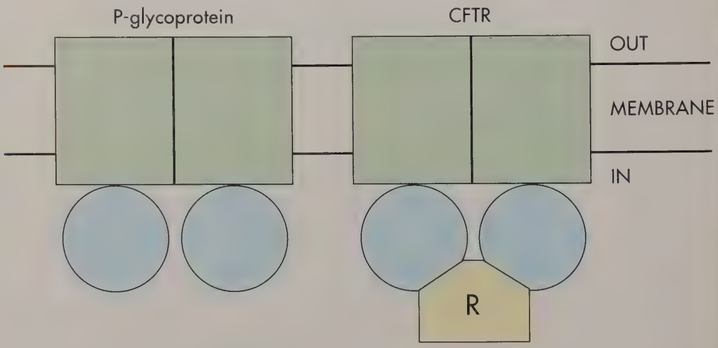
The dual identity of P-glycoprotein was revealed when a cloned gene for the protein was introduced into cultured fibroblast cells, so that large amounts of P-glycoprotein appeared in the cell membrane. With their new protein, these cells acquired increased ability to transport chloride ions across the membrane. Everything that knocked out transporter function, also stopped chloride ion movement - for example, an "antisense" oligonucleotide of the P-glycoprotein gene, and the drug forskolin inactivated both properties.

Research is continuing to develop a model of P-glycoprotein activity. One hypothesis is that the preponderance of positively charged amino acids on the external face of the molecule creates a pore through which negatively charged chloride ions pass. To test this theory, mutant forms of P-glycoprotein are being compared in which some of the positive amino acids are being substituted by negatively charged ones. A similar approach is revealing which parts of the molecule are involved in drug transport, and which are required for chloride ion movement.

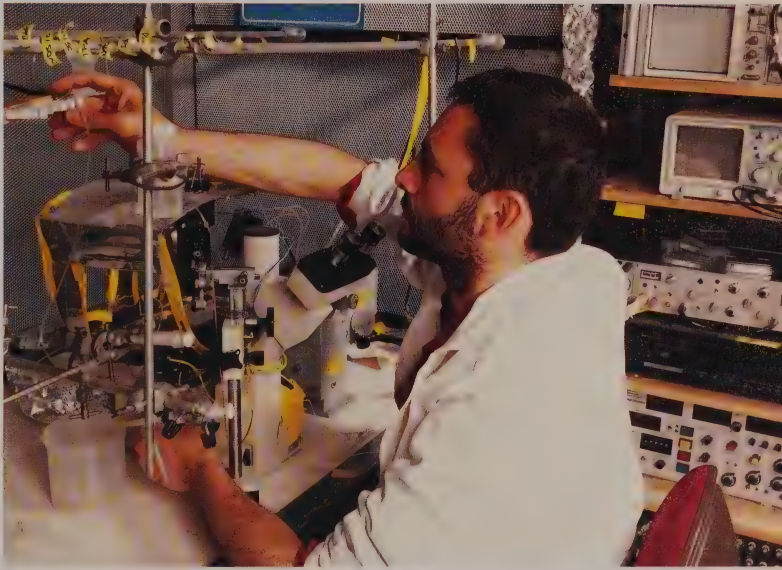
Transporter of antigenic peptides

Most animal cells can alert the body's defence system if they are infected by pathogens such as viruses. The virus needs to parasitise the cell's own machinery in order to reproduce itself. The cell displays fragments of the virus on its surface where they are recognised by specialised T lymphocytes that kill the cell, thus limiting the multiplication of the virus and,

Family likeness - members of the ABC family of proteins have a common topology. Typically, two domains of the protein span the membrane, and two are on the inside. Each of the latter has a site for binding ATP, and these two domains are very highly conserved. But there are differences in function - CFTR, for example, requires the ATP to be broken down, but P-glycoprotein requires only ATP binding. CFTR also has a fifth domain called R for regulatory.



Advances have been made in techniques for measuring the electrical currents across membranes, that arise from the passage of ions through channels in the membrane. Putative channel molecules can be introduced into cells; and the effects of environmental conditions on channel operation can be tested.



thereby, the spread of the infection to other cells or to other individuals.

Scientists at IAPGR, in collaboration with the Institute of Molecular Medicine, Oxford have implicated a transporter in the process whereby fragments of viral proteins, derived from proteins generated in the cytosol, become displayed at the cell surface. Cells also use this same mechanism to exhibit fragments of "self" proteins, but the display of these fragments does not normally lead to cell killing because of an "education" process (particularly active in the thymus) which leads to the deletion or inactivation of self-reactive T cells. This "self-tolerance" mechanism, however, sometimes breaks down, so the new findings on the display of protein fragments to T lymphocytes might lead to a better understanding of genetic susceptibility to both infectious and auto-immune diseases.

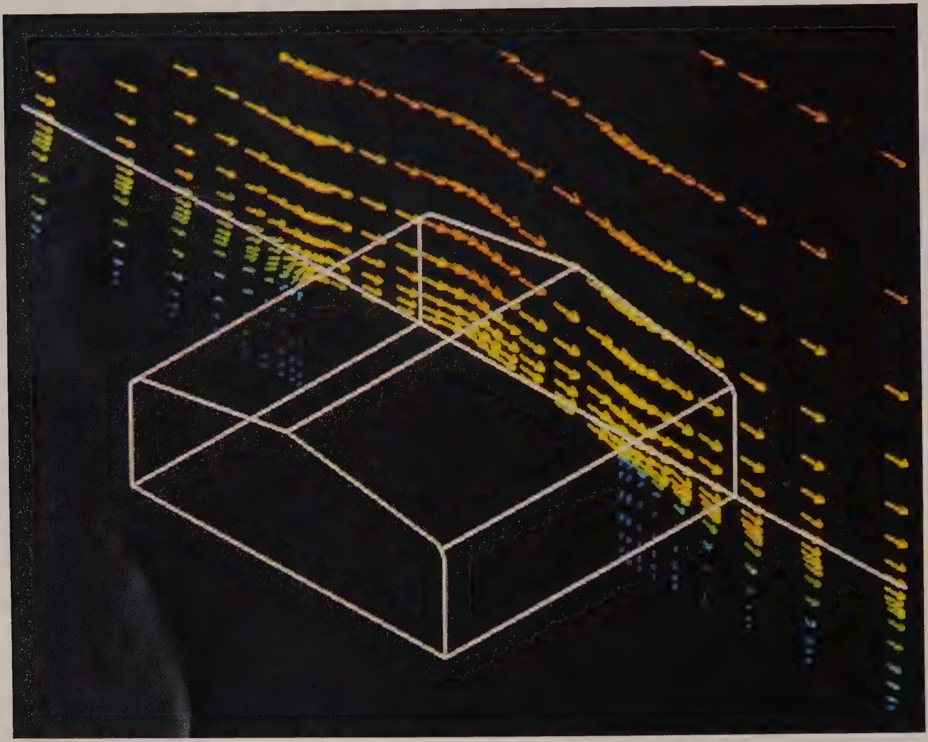
Killer T lymphocytes recognise pieces of foreign protein, typically fragments of 8-9 amino acids, only if these are incorporated with protein molecules known as MHC class I. These molecules are assembled inside the endoplasmic reticulum (ER) of cells, so peptides derived from invading viruses or bacteria in the cytoplasm have to cross the ER membrane. Pieces of "self" proteins have to make the same journey.

A breakthrough in understanding this process came when the IAPGR researchers and their Oxford collaborators showed that cells able to fragment invading protein, but defective in presenting the fragments in MHC class I complexes, could be repaired by equipping them with a new gene coding for a transporter protein. In fact, they found that two genes are involved - each codes for half of the ABC-type transporter needed to carry peptides across the ER membrane. Significantly the genes for these proteins are located in the Major Histocompatibility Complex (MHC) close to the genes for the display molecules described here (MHC class I), for another class of display molecule involved in the stimulation of a distinct set of T cells, the helper T lymphocytes, and for genes that may be involved in the fragmentation of self and pathogen-derived proteins in the cytosol (the proteasome subunits).

In rat cells, one transporter gene can exist in two forms. These appear to be associated with the type of peptides that are transported - one form transports peptides rich in hydrophobic amino acids, the other more hydrophilic peptides. This apparent selectivity in the assembly of MHC class I has important implications. It is possible that, for biochemical reasons, it is not possible to design a transporter which can efficiently transfer peptides of every conceivable amino acid sequence, and that in the long evolutionary battle between pathogen and animal it has become expedient for the latter to make available transporters of different selectivity in order to prevent a pathogen from evading detection. This may be informative for those working on peptide vaccines - these would be effective only if they are acceptable to the transporter as well as to the MHC class I molecule on which they would be displayed.

COMPUTER TAKES THE LOAD FOR FARM BUILDINGS

Over £40 million worth of structural damage to agricultural buildings occurs on average each year in the UK as the result of wind damage. A better understanding of how windload is generated could help reduce such damage by providing designers with a better estimate of damage risk.

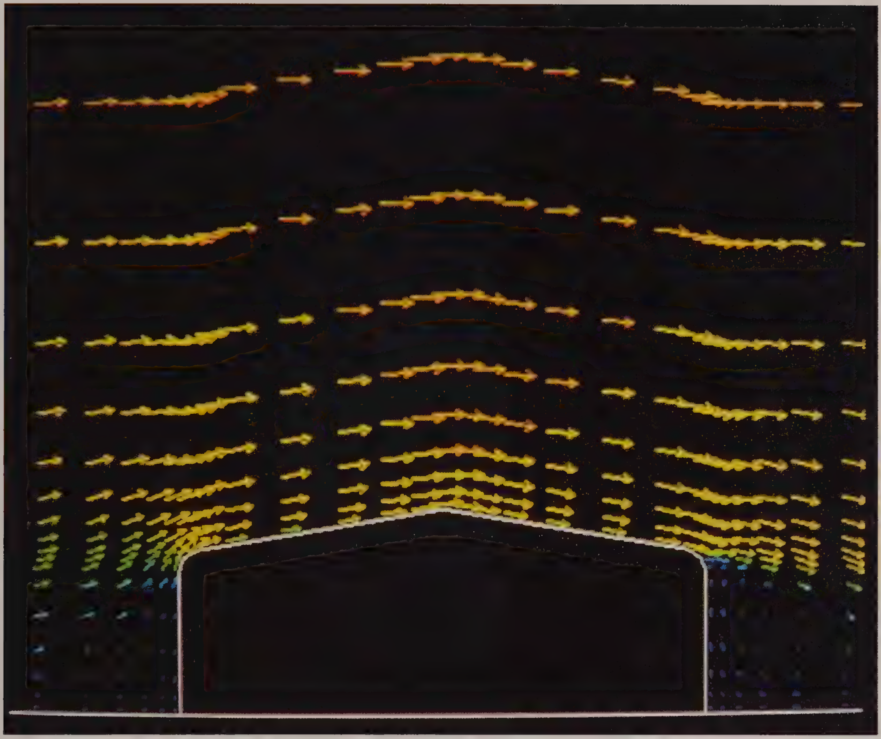


The AFRC Silsoe Research Institute plays a unique and world leading role in understanding the mechanisms of windload generation on farm buildings. This stems from a farsighted decision in the 1970s to analyse windloading on full-scale buildings - at a time when there was near universal adoption of wind tunnel testing of model structures.

An extensive database has been compiled based on measurements from over thirty real farm buildings and on a specially constructed test building at Silsoe. What makes this database so valuable is that wind tunnel simulations have consistently failed to predict accurately the windflow patterns observed on full-scale buildings. For example, a collaborative study between Silsoe researchers and the University of Western Ontario revealed that model systems can significantly underestimate uplifts, and so underestimate suction forces occurring over the roof of a building.

Ways of improving the predictive value of results from wind tunnel studies, and the development of alternative computational modelling systems are important aspects of research at Silsoe.

The Silsoe data have also allowed the validity of different approaches to predicting structural loads - such as those adopted in many national standards - to be evaluated and compared. In some instances it has been possible to identify inadequacies in consideration of building geometry, and in assessments of internal pressures.



Air flow around an agricultural building visualised by computer.

Much of the Silsoe research on windloading continues to be funded by MAFF. As well as contributing to national and EC standards on building design, the results enable construction companies and manufacturers to eliminate design flaws - one notable example has been improvement in the design of plastic tunnels. The data also allow the effects of changing the geometry of a building to be evaluated. For example, using the test building at Silsoe, windloads on a modern curved eaves structure have been compared with those on a traditional sharp line gutter eaves. Load distribution was affected over most of the roof span, beneficially near the windward eaves where damage normally occurs, but detrimentally with higher suctions over the ridge.

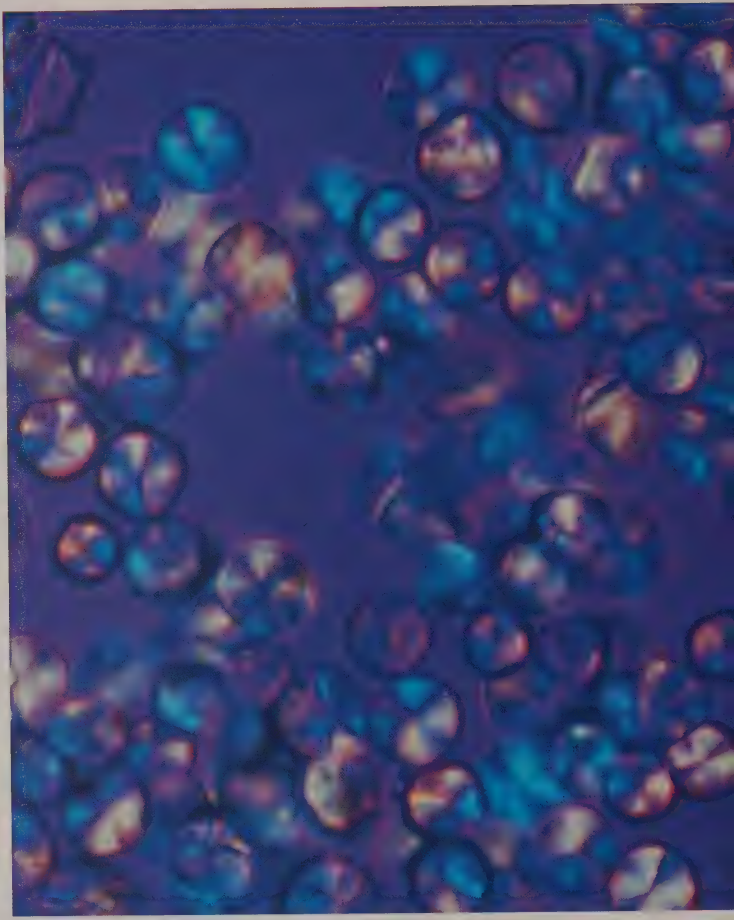
Recently, and with some funding from the Science Budget, progress has been made in using a numerical modelling device - computational fluid dynamics (CFD) - to predict patterns of wind flow and load. A software package called Phoenics is used in this research. From data about the geometry of a building and air speeds, the computer draws the vectors experienced by different parts of the building and indicates their magnitude. Consequences of changes in building design or other factors can be visualised by keying the changes into the program and observing alterations in the pattern of vectors. This technology is also being used to predict patterns of air flow in animal housing - see page 42.

In a collaborative study with the City University and Surrey University, new ways of predicting windloading are being explored using a combination of data from wind tunnel tests, full-scale and CFD studies. There is also collaboration with the University of Auckland, New Zealand to investigate the potential of CFD in windload prediction.

Silsoe engineers collaborate closely with the Buildings Research Establishment of the Department of the Environment. But their expertise is sometimes called upon in more surprising ways: in the past they have investigated and measured windloads on the perimeter walls of prisons, in a study for the Home Office!

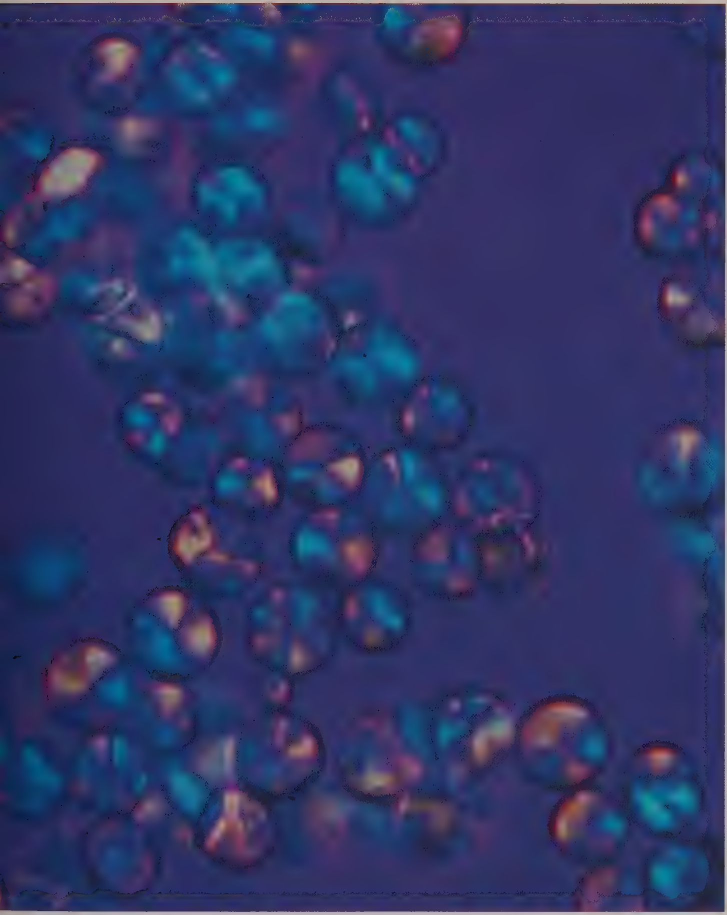
DESIGNER STARCHES

Starch is the principal seed storage polysaccharide of plants and a major dietary component. Its industrial applications include the manufacture of paper, biodegradable plastics and textiles, the encapsulation of pharmaceuticals, use as a thickening, gelling or texture-modifying agent in foods, and the generation of glucose syrup for use as a sweetener. Different manufacturing processes require starches of different physical properties. These properties are currently generated by exploiting the variations which occur between starches from different sources (for example, starch from potato tubers has a different structure, and hence different physical properties, from starch from cereal grains), and by making chemical modifications of starches. Research at the John Innes Institute (AFRC Institute of Plant Science Research) and at the AFRC Institute of Food Research is paving the way for "designer starches" which will increase the versatility of starch as an industrial raw material: these starches will be created via genetic manipulation of plants to meet specific industrial requirements, and to open up new uses for starch.



At the John Innes Institute (JII), scientists have identified and cloned the genes that code for enzymes responsible for starch biosynthesis in the pea embryo - a model experimental system. In principle, knowing how each of these enzymes contributes to starch structure and composition, and how this affects its properties, will allow the orchestration of gene activity to synthesise starches of specified structure and composition.

Implicit in the idea of designer starch is knowledge about what physical and chemical properties are needed to give particular attributes such as melting characteristics or the glass transition behaviour which determines whether a product is brittle or rubbery at a particular temperature. At IFR, researchers are correlating functional attributes of starch with its structure and composition. JII and IFR are collaborating in an ECLAIR project on structure/function relationships in pea starch. New pea mutants with altered starch structure have recently been produced at JII. These will be valuable both in understanding the structure/function relationships of starch and in elucidating the mechanisms which



Research is identifying how the physico-chemical properties of starch govern important behavioural characteristics such as crystallisation.

determine structure during starch synthesis.

Starch is composed of amylose, a linear polymer of glucose units, and amylopectin, in which the chains are branched. A single starch grain is not homogeneous: different parts containing different structures that reflect changes in synthetic pathways during development. This heterogeneity has hampered analysis of structure/function relationships. At IFR new experimental approaches are allowing extrapolation of results obtained with fragments of starch to the whole polymer.

The effect of branch length on crystallisation and subsequent mechanical properties is being identified.

Two types of enzyme are involved in starch biosynthesis: starch synthase, which adds glucose units to the growing chain and starch branching enzyme (SBE) that creates branches in the polymer. The enzymes exist in multiple forms that have different kinetic properties and affinities: pea embryo has three synthases and two SBEs. Scientists at JII have cloned the genes for these enzymes and are now characterising them. They are examining mutants, including one that lacks one of the SBEs, to see how changes in enzyme activity influence the amount and structure of starch in the embryo. With a major commercial partner they are studying how different levels of activity of the individual enzymes affect starch synthesis in potato, using potato plants in which forms of the biosynthetic enzymes in the tuber have been altered by genetic manipulation. These studies will allow the relationship between particular forms of the biosynthetic enzymes and specific aspects of starch structure to be determined. A model which will allow directed alteration of starch structure through genetic manipulation can thus be built up. In addition to manipulation of the biosynthetic enzymes, starch structure may also be altered in the future by introduction into starch-synthesising organs of starch-degrading enzymes and bacterial enzymes which create differently-branched polymers.

At IFR, the role of degradative enzymes is being explored with particular reference to the dietary fate of starch. With MAFF funding, the properties that make starch "resistant" to enzymic attack in the small intestine - and thus result in its passage as a fermentation source to the colon - are being explored. This is important for two reasons. Firstly, it might allow design of dietary starches with particular digestibility characteristics (the development of an enzymic method for analysing the resistant nature of starches is described on page 51). Secondly, it is identifying resistant starch that might be used to "coat" pharmaceutical products to ensure their passage through the small intestine for activity in the colon (this is being explored with BTG).

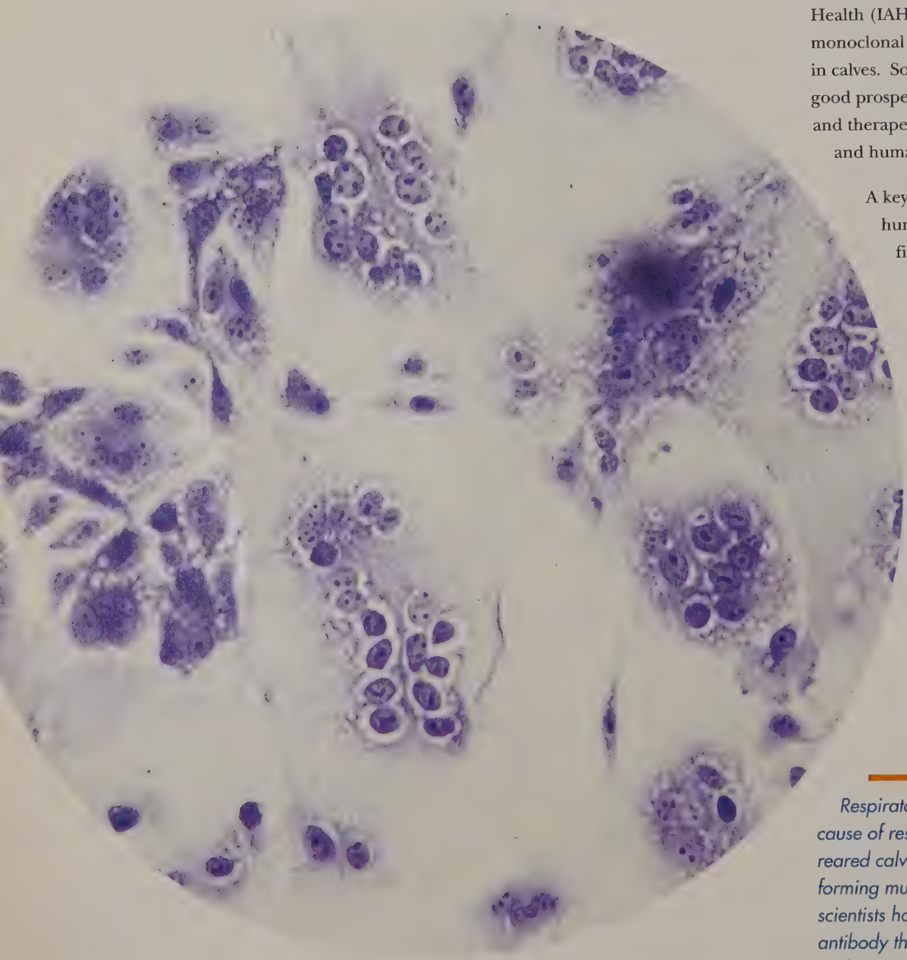
ANTIBODIES AGAINST VIRAL DISEASE OF CALVES AND BABIES

Antibodies are protein molecules that specifically bind to, and disable, "foreign" i.e. antigenic material. The clinical use of specialised antibodies (monoclonal antibodies) targeted, for example, at cancerous cells, defective immune cells, viral and bacterial pathogens has tantalised scientists for the past decade. There have been two major obstacles. Firstly, generating monoclonals from human antibody-producing cells has proved very difficult; and secondly, the more-easily derived monoclonals from mouse cells cannot be used therapeutically because they are rejected as "foreign" by human cells.

AFRC scientists working on respiratory syncytial virus (RSV), which is a major cause of respiratory disease in calves and young babies, have collaborated with scientists from Scotgen Ltd, Aberdeen, who have pioneered new ways of re-modelling antibodies so that they escape detection by the human immune system. The result is the world's first "humanised" antibody to prove effective in combating disease.

At the same time, the AFRC group, which is based at the AFRC Institute for Animal Health (IAH), has developed a bovine monoclonal antibody effective against RSV in calves. So for the first time, there are good prospects of effective prophylactic and therapeutic treatments both for calves and human babies.

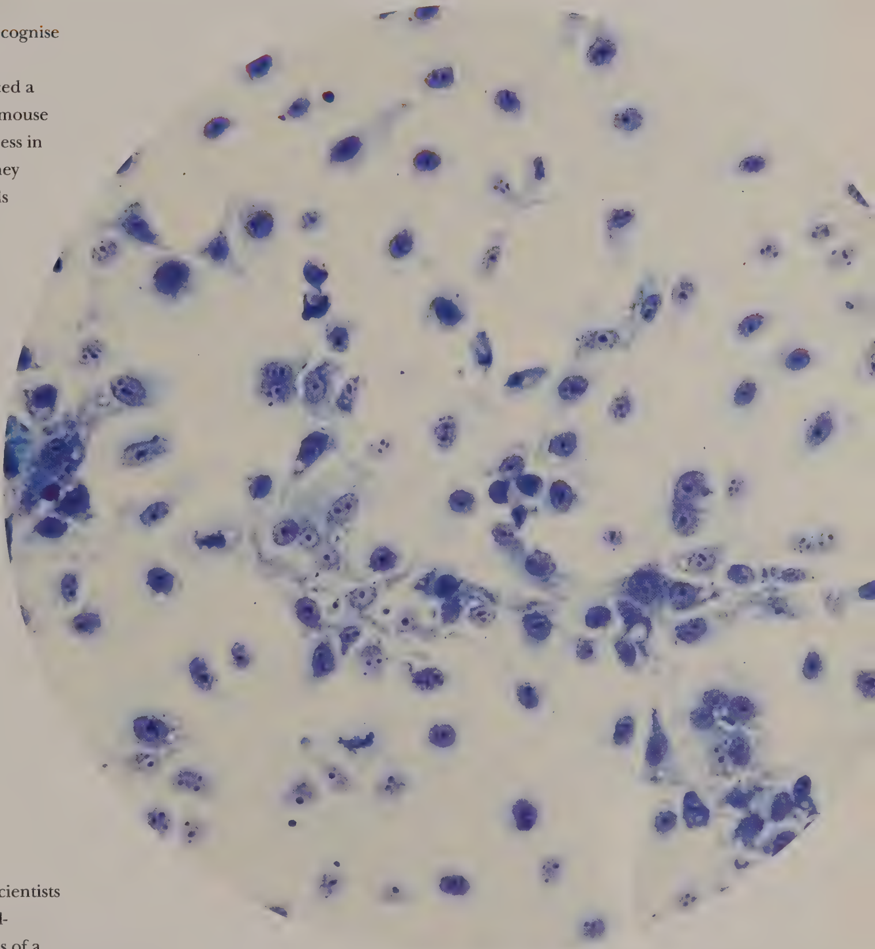
A key step in constructing the humanised antibody, and in finding an effective bovine antibody, was the identification of those regions of RSV that elicit a protective immune response, and so might be specifically targeted. This was particularly critical in the light of evidence that some RSV vaccines have increased the severity of respiratory disease.



Respiratory syncytial virus is a major cause of respiratory disease in intensively reared calves. Infected cells fuse (left) forming multi-nucleated giant cells. AFRC scientists have identified a monoclonal antibody that protects against disease and prevents cell fusion (right).

Target sites on RSV

Different monoclonal antibodies recognise and bind to different regions of an antigen. The IAH scientists produced a variety of anti-RSV monoclonals in mouse cell lines and tested their effectiveness in protecting mice from infection. They found that some of the monoclonals to either of two glycoproteins on the surface of the virus afforded complete or at least partial protection. These were antibodies to the fusion (F) protein and attachment (G) proteins. Whereas some of the anti-G molecules were effective in preventing infection, but not able to clear an existing infection, some of the anti-F antibodies were particularly protective, both preventing and clearing infection. These antibodies have the strongest clinical and veterinary potential. A bovine anti-F monoclonal tested in calves, has proved highly effective against RSV.



A "humanised" anti-F antibody

The idea behind the "humanising" technology developed by Scotgen scientists is to take the relatively small, but all-important antigen-recognising parts of a monoclonal antibody - in this case from mouse cells - and substitute them into a human antibody. The resultant antibody retains the specificity of its mouse precursor, but is overwhelmingly human in composition so it is not rejected by the human immune system.

One of the highly protective mouse-derived anti-F monoclonals, identified in the AFRC trials, has been grafted to a human antibody using this technique. The first humanised antibodies produced in this way did not bind virus properly and it was necessary to correct the 3-dimensional structure of these antibodies. When just 3 amino acids were substituted, a fully functional antibody resulted, just as active against RSV infection as the original mouse antibody. A single dose of 1.25 mg/kg body weight prevented infection in mice when given 24 hours before infection, and cleared an established infection. Now licensed to SmithKline Beecham plc, this antibody, which contains only 3% mouse-derived material, will soon undergo clinical trials.

NOVEL NMR TECHNIQUES FOR MONITORING MASS TRANSPORT IN FOODS

The way bread goes stale is an example of how quality is affected by the redistribution of water over distance scales ranging from the molecular to the macroscopic. Current understanding of the mechanisms of water (and solute) transport in food materials is still at a relatively primitive level, in part due to the difficulty of measuring local diffusion and flow in heterogeneous systems. Scientists at the AFRC Institute of Food Research are developing two novel nuclear magnetic resonance (NMR) techniques using recently acquired microimaging equipment. These techniques make use of spatially varying resonance frequencies imposed by the application of magnetic field gradients. They promise to alleviate some of the problems in understanding transport processes by providing direct measurements on a range of length scales.

An NMR image of water proton density of a sample of starch being heated in water (brown = high density; dark green = very low density). This non-invasive technique can be used to follow the process as the outer region gels and dries the inner region.

NMR microimaging

The redistribution of water in a food undergoing drying, rehydration, cooking or just storage can be monitored directly by NMR from changes in the spatial dependence of its signal intensity, provided allowance is made for signal loss during generation and acquisition of data. Spatial resolutions down to ca. 10 micrometres are possible in ideal circumstances, but more usually signal-to-noise problems limit resolution to a few hundred micrometres depending on the nature of the sample. Water transport coefficients can be derived from the time dependence of the water distribution by fitting with appropriate theoretical models. With a model sample consisting of packed cellulose powder in a cylindrical sample tube, initially saturated with water, the water proton spin density can be periodically imaged, giving a measure of water distribution over time. Even if food material is always fully saturated with water it is still possible to use microimaging methods to measure water transport by immersing the sample in deuterium oxide (D_20) and imaging its influx by diffusion.

IFR scientists are currently extending the microimaging method to examine transport of low molecular weight solutes, important for controlling microbial growth in foods.

NMR "q-space microscopy"

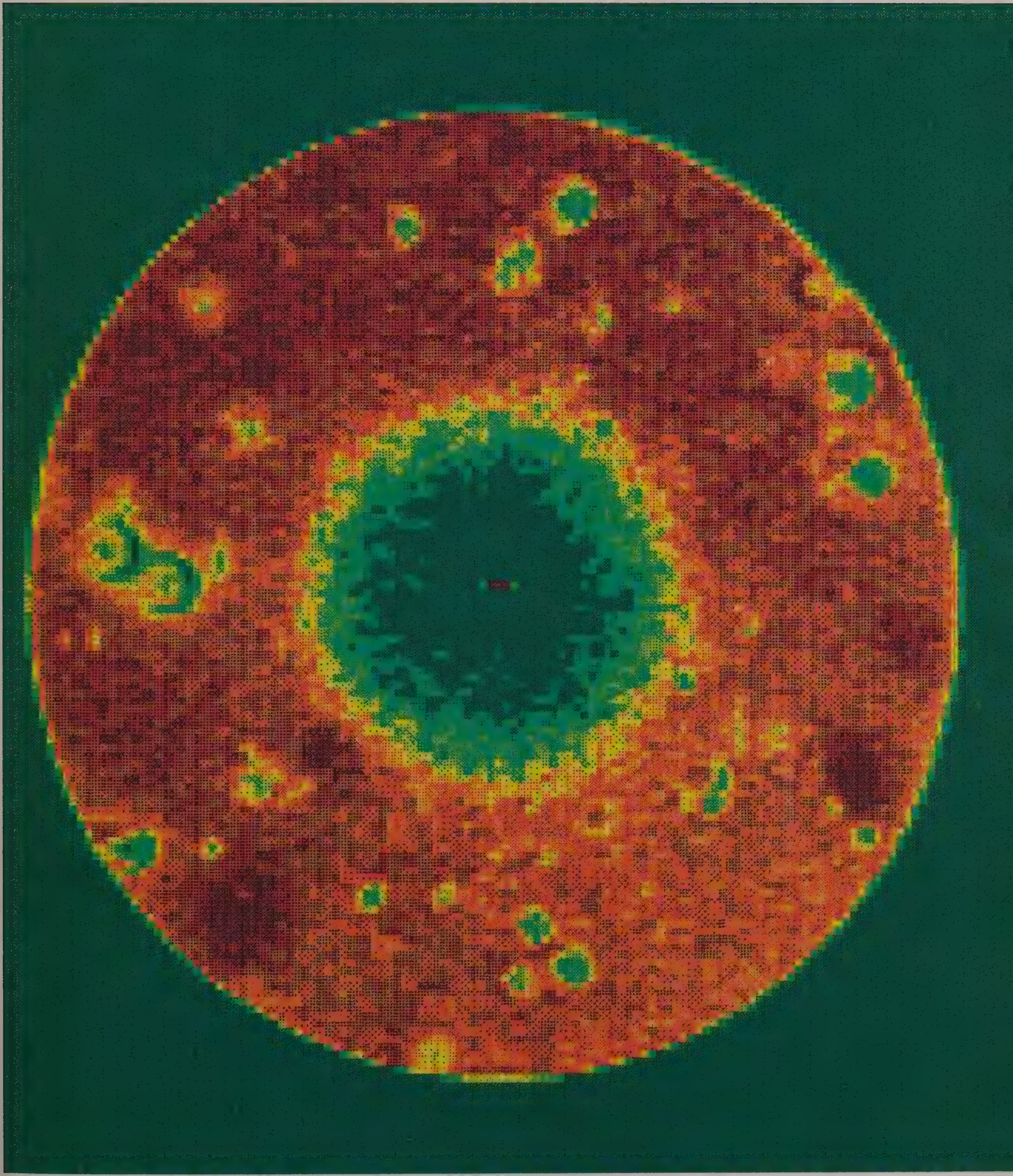
Microimaging techniques characterise mass redistribution over macroscopic distances of 0.1-10 cm. Transport over shorter distances less than about 200-300 micrometres can be measured using a complementary NMR technique called "q-space microscopy" also being developed at IFR.

A molecule diffuses randomly and as time progresses, explores the confines of its space in a manner analogous to X-ray diffraction. By measuring how the apparent diffusion coefficient of water changes, it is possible to explore the shape of its confining space e.g. a pore in a foodstuff or the shape of a plant cell. In particle scattering such as X-ray diffraction the only parameter that can be changed is the wavelength of incident light, which in the NMR analogy is the size of the field gradient. Uniquely in NMR, a second parameter may be changed - the time between the field gradient pulses. At very short times the molecule does not reach the walls of the cavity and is not therefore affected by local structure, at long time it is reflected by the walls of the cavity and therefore its displacement is a measure of its interaction with the local structure. Since the apparent diffusion coefficient (adc) depends on the apparent displacement, as time increases the adc **decreases.** By observing the effects of the time between pulses on the adc it is possible to explore the structure of the material.

So far the q-space method has been most extensively tested on a model system consisting of silica gel where conditions can be closely controlled and extensive computer simulation is relatively straightforward. However the IFR team have also had considerable success in studying water transport processes in parenchyma tissue of apple using a spherical model of a plant cell to interpret the results. All the parameters could be independently determined except for the plasmalemma membrane permeability which can be obtained by fitting data. In principle, the effects of varying osmotic stress, temperature and pH on membrane permeability to water can now be investigated.

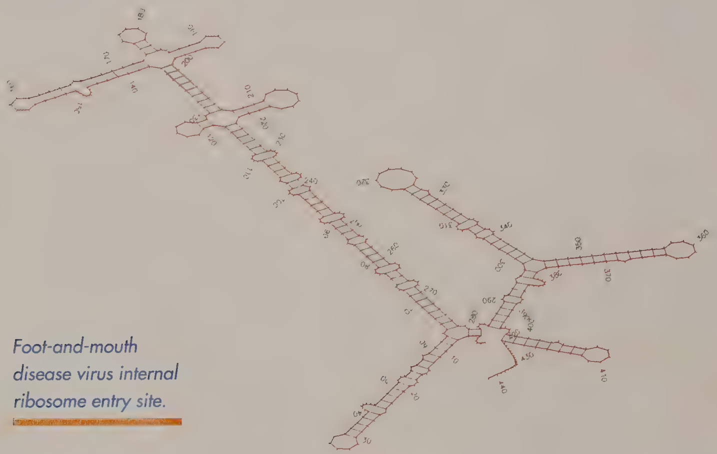
Diffusion-weighted microimaging

In theory, combining the larger scale imaging experiment and the q-space pulse sequence will permit measurements in local subregions of a spatially heterogeneous food sample, so it may eventually be possible to obtain both long- and short-time transport information in a single experiment. Preliminary results have already demonstrated the enormous potential of NMR for studying mass transport in heterogeneous food materials.



FOOT-AND-MOUTH DISEASE VIRUS - A NOVEL ELEMENT CONTROLLING PROTEIN SYNTHESIS

Genes are expressed in animal and plant cells by transcription of their encoded information (as DNA) into messenger RNAs (mRNA) and subsequent translation of this information into protein following transport of the messages to the cytoplasm. Normally mRNAs have special "cap" structures at their 5′ end, where ribosome subunits bind before scanning along the molecule to find the first AUG triplet of bases which defines the start of translation. From this point the ribosomes, together with transfer RNAs, decode each triplet codon of the message in turn and, in the process, add the appropriate amino acid to the growing polypeptide chain. Eventually the ribosome reaches a triplet which signals "stop" and translation of the mRNA ceases.



Foot-and-mouth disease virus internal ribosome entry site.

The messages encoded by the mRNAs of infecting viruses are generally translated in much the same way since they depend on the host cell's machinery, but recent work on picornaviruses (e.g. poliovirus, foot-and-mouth disease virus, and encephalomyocarditis virus) has indicated a radically different mechanism by which mRNAs can be translated. For example, the 5' non-coding region of the mRNA of foot-and-mouth disease virus (FMDV), which precedes the portion which is translated, is particularly long and includes amongst other structures a stretch of 435 nucleotides just upstream of the coding segment which directs **internal** initiation of translation. With this sequence in the mRNA ribosomes do not have to bind at the 5' end but can instead initiate translation by binding to the mRNA directly at this special site. These structures have been called internal ribosome entry sites, or IRES for short. During infection the IRES enables the FMDV mRNA to continue to be translated after the virus has shut down translation of normal cellular mRNA through the inhibition by the FMDV L protein of cap-dependent mRNA translation.

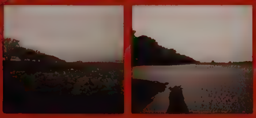
Normally mRNAs contain single segments of translatable information and simply joining two mRNA sequences together results in the efficient translation of only the first coding sequence. Recently, artificial mRNAs with two blocks of translatable encoded information separated by the IRES have been produced at the AFRC Institute for Animal Health (IAH). The first block is under the normal cap-dependent translational control but the second one is downstream of the FMDV IRES. Such "bicistronic" mRNAs are efficiently translated to produce both proteins. Furthermore, if cap-dependent translation is inhibited by expression of the FMDV L protein, the translation of the upstream protein-coding sequence stops while IRES-directed translation of the second protein coding sequence continues.

Knowledge of the sequence of the IRES allows predictions to be made of its structure and the identification of potentially important components in relation to its functions. Such predictions suggest the IRES is composed of a series of base-paired stems and single stranded loops. Comparison of the IRES structure in related viruses shows that in some cases the structure has been highly preserved despite extensive sequence diversity, whereas in other viruses the analogous elements are apparently unrelated in both structure and sequence, suggesting that different types of element can perform the same function. Experiments at IAH and elsewhere involving bicistronic mRNAs are allowing detailed dissection of the IRES and indicating those regions which might be directing ribosome binding or determining the selection of the correct initiating AUG codon. Since the discovery of the IRES in picornaviruses, an analogous element has been found in a cellular mRNA encoding a protein called BiP. The presence of this element enables the continued translation of BiP in poliovirus-infected cells. The presence of IRES elements in cellular mRNAs may be more widespread than this, reflecting different mechanisms of translational control in normal cellular processes.

USING AGRICULTURAL *resources* MORE EFFICIENTLY

In AFRC, we are working with commercial companies and with our partners in the EC to ensure that agricultural resources are used as efficiently as possible to produce food and raw materials for industry.

- *We have assembled the world's most detailed genetic map of wheat with over 700 markers. The successful mapping of agronomically important genes allows breeders to select for desirable traits in the laboratory, early in the breeding programme.*
- *We are exploring the biological and engineering principles needed to develop sustainable systems for using all the components of crops efficiently to produce food and non-food materials. Examples include fibre extraction from cereal and other straws and short rotation coppicing for biomass.*
- *The full potential of many crop species to act as bioreactors producing industrial raw materials has not yet been realised. We are combining the techniques of molecular biology and conventional plant breeding to modify the oilseed profile of crops, enhance the industrial usefulness of oats and develop novel sources for industrial proteins and carbohydrates.*
- *We are exploiting theoretical studies on population genetics to improve the design of breeding programmes for livestock.*



THE GENETIC MAP OF WHEAT - A NEW TOOL FOR PLANT BREEDERS

Improved crop performance has been one of the most spectacular successes of post-war agriculture. As more was learnt about the genes controlling different traits, so plant breeders incorporated those conferring agronomic value into commercial varieties. This process may now be accelerated through the use of genetic maps that will assist breeders to select for the presence of desirable genes in the laboratory in the early stages of a breeding programme.

In the past, cereals have been bred predominantly for higher yield and improved grain quality. But as we learn more about the genetic control of other important traits, breeders may also choose to select for a range of characteristics better suited for more extensive, resource-conserving and environmentally sensitive farming - and genetic maps should allow them to do so much more rapidly than has been possible in the past.

Researchers at the Cambridge Laboratory (AFRC Institute of Plant Science Research) have assembled the world's most detailed genetic map of wheat. The compilation is painstaking: firstly because wheat is genetically complex, with 21 pairs of chromosomes and secondly, because genetic maps must be very detailed if they are to be of practical use for wheat breeders.

The principle of mapping is to identify and analyse the segregation patterns of a large number of markers or "landmarks" distributed throughout the genome. Most of these markers represent sequences that can be probed using short cloned fragments of DNA. Genes of agricultural interest are then mapped relative to the location of the markers. Once this has been done, breeders can select for the appropriate marker - often a much easier,

Pre-harvest sprouting - the genes controlling this and other traits affecting pre-harvest quality loss have been mapped. Linked markers will allow breeders to select for resistance in every season, not only in years with high rainfall prior to harvest.

cheaper, quicker and more precise option than having to grow the plants and rely on plant appearance for selection. The wheat genome, with about 16 billion nucleotide pairs, is massive relative to most crop species. The AFRC scientists now have some 750 markers along the chromosomes and have mapped many important genes.

Among the wheat genes mapped are the GA-insensitive *Rht* dwarfing genes, which were introduced into British wheats in the 1960s to help produce high yielding varieties able to withstand heavy fertiliser applications without lodging (stem collapse). In future, genes controlling straw length, internode pattern and fibre quality may be manipulated to enhance straw value for non-food applications. It would then be technically straightforward to combine desirable attributes for grain quality and straw quality in the same variety.

Genes for resistance to diseases, such as eyespot and powdery mildew, have also been mapped. In the long term, the development of crop species that have a stable genetic resistance to a range of pests and diseases offers farmers the desirable option of lowering pesticide input without sacrificing yield and quality.

Genes for abiotic stress resistance, e.g. salt and drought tolerance, have also been mapped. Their introduction into commercial varieties could increase options for managing crops in irrigated/drought affected areas, particularly in developing countries; and they may become important to UK agriculture if climatic conditions become warmer and drier as commonly predicted.

This work at the Cambridge Laboratory has involved considerable industrial collaboration with sponsorship by Agricultural Genetics Company Ltd, ICI plc, Ciba-Geigy plc, Nickersons International Seed Company Ltd, Plant Breeding International Cambridge Ltd and Cambridge Plant Breeders. Work is continuing to produce yet more extensive and informative markers on the map.

Apart from its use in conventional plant breeding technologies, the genetic map of wheat holds enormous potential for directing the biotechnological improvement of crops. This will be particularly so once recent breakthroughs in the genetic transformation of wheat, one of the most difficult crop species to genetically manipulate in this way, are converted into practical technology.

In addition to the wheat genome mapping exercise similar work is in progress on barley, rye, pea, *Arabidopsis* and *Brassica* in IPSR and, with funding from the ODA, on millet and rice.

The wheat gene maps will allow marker-aided selection for some agronomic traits in early generations, thereby enhancing the efficiency of breeding for crop improvement.

WHOLE CROP UTILISATION

The practice of growing crops predominantly for high yields of a single component - for example, wheat to produce gluten-containing flour for breadmaking, with starch as a by-product - faces two challenges. First, there is economic incentive for farmers to diversify; and second, there are environmental pressures to find renewable sources of raw material for industry.

Biorefineries

Advances in harvesting technology and process design and control, together with a better understanding of opportunities for biological modification of plant materials, provide a scientific basis for meeting these challenges. In biorefineries - roughly analogous to petrochemical refineries - whole crops might be fractionated and processed. For example, a cereal crop might be fractionated initially into straw and grain. The grain component could be fractionated into fibre, protein, oil and polysaccharide components, again with options for further processing. The use of straw for industrial purposes is, however, considerably enhanced if leaves are separated from stems. Straw stems are of about the same composition as wood and could supply much of the wood pulp required for paper making as well as fibre needed for hardboards.

Leaves are unsuitable for industrial use but excellent for animal feed, ranking alongside good quality hay or silage. Furthermore, work at the SOAFD-funded Rowett Research Institute has shown that, unlike stems, straw leaves are very receptive to enzyme treatment such as mixtures of cellulases and xylanases. It is quite possible that sufficient fibre can be solubilised to create good feed for monogastric animals, possibly even including fibre for human consumption. This depends on finding a successful, cheap method of separating the botanical fractions. It also appears possible to improve both leaves and stems by selection for their value as animal feeds and as industrial raw materials.

Linseed - its potential as a source of industrial grade fibre is being explored.

At the AFRC Silsoe Research Institute, systems modelling is being used in an EC-supported project to identify the flow of materials, energy costs and profitability of a whole crop biorefinery. Operational design and costings for labour, energy, machinery, transport and so on are being analysed, in collaboration with researchers in Denmark, Ireland, Germany and Greece. Emphasis is on major crops such as oilseed rape, for which potential processes include enzymatic upgrading of oils and extraction of a protein syrup for use in animal feeds. Also included in the study is *Miscanthus*, a fast growing species with potential for biomass production.

Linseed is an example of a crop currently grown exclusively for one product, oil - but with potential for another, industrial grade fibre. The UK crop has grown in recent years to over 100,000 ha. Although linseed straw is shorter with coarser fibres than its close relative flax, it offers a low-cost alternative to synthetics for many applications, including industrial textiles, moulded fibre products and fibre-board. MAFF supported research at Silsoe has led to the design of three novel engineering devices (patented by MAFF) to extract fibres from linseed straw. These in turn, align, crush and finally separate the fibres from the non-fibrous inner parts of the stem. Related projects at Silsoe include the development of high-speed mechanical separation techniques for fractionating plant parts, novel coppice harvesting and novel slicing and compacting processes for straw. This work is funded from a variety of sources including the LINK programme, the Department of Energy and the EC.

Biomass

Short-rotation coppice forestry has potential as a renewable, non-fossil and carbon dioxide-neutral fuel. The feasibility of short rotation willows and *Miscanthus* as biomass crops is being explored within the AFRC Institute of Arable Crops Research.

A novel straw slicing machine, designed at the AFRC Silsoe Research Institute, which is being tested in a pilot scale pulping plant.

Selected willow clones have been identified that are suited for particular soil types. The influence of planting density on yield and weed control has been investigated and the importance of weed control in crop establishment demonstrated. Current research is aimed at disease control, crop physiology and conservation of the 700 clones within the National Willow Collection.

The potential profitability of different biomass systems is being analysed by predictive mathematical modelling at the AFRC Silsoe Research Institute. Although profitability is not markedly affected by costs of establishing and maintaining the crop, some factors, notably costs of harvesting, and chipping, capital investment in plant for power generation, generating efficiency and price obtained for electricity generated, are critical. One model of willow coppicing indicates a negative cash flow for the first three years, with initial investment costs recovered by the ninth year. Coppices attract the Forestry Authority's "Woodland Grant" scheme and can have a productive life of up to about 30 years.

Two factors are responsible for the increasing interest in new types of crops: the presence in many developed countries of substantial surpluses in some commodities; and more global concerns about the need to find renewable sources of industrial raw materials, for example, to replace fossil-derived fuels.

New oils for industry

High-yielding oilseed crops are grown almost exclusively for edible purposes - the major species in Europe and North America being soybean, rapeseed and sunflower. In principle, gene technologies could be used to modify these crops so that they produce a wider range of seed oils including those valuable in the plastics, pharmaceutical, lubricants, cosmetics and other non-food industries.

The industrial usefulness of oils depends on the type and mixture of fatty acids that they contain. Modifying this fatty acid profile will require knowledge of the biosynthetic pathways of each fatty acid and of the genes that code for the enzymes of the pathways. Scientists at the Cambridge Laboratory of the AFRC Institute of Plant Science Research are using this approach to study two major classes of enzyme involved in oil biosynthesis: fatty acid modifying enzymes, which are needed to produce the desirable fatty acids; and acyltransferases, to ensure that these become incorporated into the oils. One enzyme of the first category is Δ_6 stearate desaturase, which produces petroselinic acid, an isomer of oleic acid. Oleic acid is ubiquitous in edible oils. Petroselinic acid is valuable in the manufacture of detergents and plastics. It can be easily cleaved by oxidative ozonolysis to yield two valuable products, i.e. lauric acid and adipic acid. Adipic acid is currently derived from fossil oil using a lengthy and expensive chemical refining method. The use of petroselinic acid would mean that adipic acid could be produced from a renewable source. The market for adipic acid in the UK is estimated at over £100M *per annum.*

Some species of the *Umbelliferae* family, including Coriander, produce seeds rich in petroselinic acid. The IPSR scientists are working to isolate and clone the gene for Δ_6 stearate desaturase from Coriander as a prelude to attempting its transfer to oilseed rape. Similar strategies are being deployed with enzymes involved in biosynthesis of ricinoleic acid - valuable for production of nylon polymers, coatings and surfactants, cosmetics and pharmaceuticals - a total UK market estimated at over £50M p.a.; and erucic acid - used in solvents, lubricants and high grade engineering plastics. Some of this research is funded by MAFF.

Another strategy, being considered by scientists at the AFRC Institute of Food Research, is to use yeast cells as bioreactors for the production of short chain fatty acids. Yeasts use the enzyme fatty acid synthase (FAS) to make palmitic acid. The corresponding FAS in rat can synthesise shorter chain fatty acids through interaction with another enzyme, thioesterase II, which acts like a molecular knife cutting off the growing fatty acid chain. One could introduce rat thioesterase II into yeast and see whether or not it can interact with yeast FAS. Another possibility is to express both rat FAS and rat thioesterase II in suitably engineered yeast strains. The filamentous fungus *Entomophthora* sp. which produces medium chain fatty acids is also being incorporated into the study. Either of these approaches might offer a cheaper alternative for industrial production of some short chain fatty acids than current chemical synthesis.

A gene from Coriander, essential for synthesis of industrially useful fatty acids, has been isolated and cloned.

New oats for new markets

Oats comprise 2-3% of the total UK cereal crop. But the development of high-yielding naked oat varieties with very good nutrient profiles is opening up new markets that might substitute for some imports.

Plant geneticists at the AFRC Institute of Grassland and Environmental Research, Aberystwyth, funded by MAFF, H-GCA and Semundo Ltd, have developed both winter and spring naked or huskless oats. Since 1989 two varieties, Kynon and Rhiannon, have been commercially available on contract to the Superioats Company Ltd fetching a price to farmers currently £35/t above that of barley. 4,000 t were produced in 1989, 10,000 t in 1990 and 14,500 t in 1991 with 22,000 t projected for 1992. A new variety, Pendragon, with higher yield and winter-hardiness will be available in 1992-93. All three varieties have high levels of energy-rich oil (8-10%), unlike other cereals, with a better balance of essential amino acids than wheat or barley.

Markets include: feed for racehorses and inclusion in dry pet foods, as well as the use of milled oats in muesli and oat bran products, where advantages are reduced processing costs, less broken grains and good flaking properties. Evidence that diets containing oats may reduce elevated blood cholesterol levels has spawned a number of new oat bran products - scientists at the AFRC Institute of Food Research are among those who have investigated the possible mechanisms of this apparent hypocholesterolaemic effect. Oat fibre, unlike wheat fibre, comprises about 60% of an unbranched polysaccharide gum called β glucan and it is hypothesised that this is the active cholesterol lowering component.

Oat oil has been extracted in a pilot study and possible applications in the pharmaceutical, cosmetic and food industry are being investigated.

A lupin for British conditions

In principle, the attractions of growing lupins seem overwhelming - they could substitute for imported soya bean, and with a seed content of 35-40% protein, 10% oil and a husk that is 70% dietary fibre, they have immediate uses in the animal feed and other industries. Lupins are a good break crop, and in acid soils they perform well without N, K, and P fertilisers. Lupins could compete profitably with cereals and peas; and are easy-to-harvest. But there are no lupin fields in the UK because varieties developed for Southern Europe do not mature early enough in our cooler climate; there are also doubts about winter survival.

Scientists at the AFRC Institute of Arable Crops Research at Rothamsted have used the principles of plant physiology to "design" a British lupin. In collaboration with plant breeders of INRA, France they have identified and successfully field tested a line (CH304) with the high yield, yield stability, early maturation and hardiness required for British conditions. This variety grows in a determinate fashion, i.e. a single main stem and a single order of branches. The pods are carried at the top of the plant where they can use sunlight to photosynthesise (and are easy to protect). These pods grow twice as fast as those of conventional indeterminate varieties which have to compete more with vegetative growth for nutrients and sunlight.

In field trials of autumn sown lupins at Rothamsted, conventional varieties yielded 1.2-2.4 t ha^{-1} harvested in November: the new line yielded 4.9 t ha^{-1} and was ready for harvest in September. In parallel trials in France, this line also yielded between 3.0 and 4.2 t ha^{-1}, showing its yield stability over different conditions.

Dalgety Agriculture, who are sponsoring a research student at Rothamsted, have negotiated the UK rights to the new line when it finishes registration trials in France. A British commercial lupin may be available by 1996.

Fructans as industrial carbohydrates

There is growing interest among plant breeders in the possibility of utilising fructan from higher plants. Fructan is a polymer of fructose found in about 10% of plants (principally temperate grasses and cereals, chicory, onions and members of the Asterales such as Jerusalem artichoke). Fructan polymers vary in size and structure depending on species, but are generally soluble in water and contain small amounts of glucose. They can be utilised directly as soluble fibre for food additives or can be readily hydrolysed to yield fructose for food use or for the production of hydroxymethylfurfural which can be used directly in several industrial applications.

Commercial fructan production on a small scale occurs in Belgium, Holland and Austria. Research on the chemistry, physiology and biochemistry and molecular biology of fructans is in progress at the AFRC Institute of Grassland and Environmental Research, at other sites in Europe and in the USA. This is directed towards defining the enzymic properties responsible for fructan diversity in higher plants, determining the processing properties of different fructans and expressing genes for fructan synthesis in species where it is normally absent. The relative ease of cultivation and low nutrient requirements of fructan-containing crops suggests they are good candidates for low-input production of industrial feedstocks.

LIVESTOCK IMPROVEMENT

Many commercially important traits of livestock such as growth rate, litter size and body composition are determined by the action of many genes working in concert. These genes are known as quantitative trait loci (QTL).

Commercial breeding programmes could be better designed if more was known about which genes are involved and how they exert their influence, for example, through altering energy metabolism and partitioning in animals.

There are two complementary approaches to studying QTLs. One involves mapping the location and genetic linkage of genes and is typified by the Pan-european programme to map the pig genome which is being coordinated by the AFRC Institute of Animal Physiology and Genetics Research at Edinburgh (reported in the AFRC Annual Report 1990-91). The other uses lines of animals that have been selected for particular characteristics over many generations to investigate how major differences in these characteristics may be correlated with genetic make-up.

AFRC supported research at the University of Edinburgh is exploring the genetic control of body weight and composition in mice in three pairs of lines that have been selected for over 40 generations. One pair of lines is selected on the basis of high or low body weight. The high group are almost three times as heavy at 10 weeks of age as the low weight line, but the lines show little difference in body composition.

A second pair of lines has been selected on the basis of % body fat. The high fat line is over three times fatter at 14 weeks of age than the low fat line, but the lines show little difference in lean tissue mass. The third pair of lines has been selected for differences in food intake. By studying the key metabolic changes that have occurred in the different lines, and identifying their underlying causes, it may be possible to identify the genes which have been selected in the different lines.

This research is addressing some fundamental questions about genetic selection which are important for optimising animal breeding strategies - for example, in any selection line how long does selection response last and how can its duration be influenced, by factors such as population size? That there is not a simple relation between the selection limit and population size is illustrated by the fact that the high fat mouse lines have continued to respond longer than the high body weight lines. Such information also tells us about numbers of genes affecting these traits and their relations to fitness.

The role of spontaneous mutations in maintaining variation is also being explored. Mutations which exert a large effect are often recessive. This means they are not observable until they occur in individuals which are homozygous for the mutation, i.e. inherit it from both parents. This research should provide clues about how to design breeding programmes so that livestock breeders may make the best use of mutations that occur.

A battery of genetic analyses is being used to identify genes that determine commercially important traits in livestock.

DEVELOPING A *systems approach* TO FARMING AND THE ENVIRONMENT

In AFRC, we are collaborating with academic partners, advisory bodies and commercial companies to bring an holistic approach to reducing the environmental impacts of agriculture.

- *We are combining long-term field experiments with the establishment of predictive computer models to identify lower input systems of crop production that are both environmentally and economically sustainable. Similarly, models of grazing behaviour and studies on clover-grass swards will aid pasture management.*
- *We are exploiting natural chemicals as lures to decoy pests from crops. We are using molecular biology to exploit natural bacteriocides, insect toxins and disease resistance mechanisms in plants.*
- *With EC partners, we are using IT to help eliminate pollution problems associated with animal waste.*
- *Our studies on the behaviour of native species in farmland environments will benefit both the design of integrated farming systems and wildlife conservation.*
- *We have launched a new programme to extend our research on animal welfare.*

LESS INTENSIVE FARMING AND THE ENVIRONMENT

Paradoxically, perhaps, a shift from conventional farming with its high inputs of energy and agrochemicals to lower input systems requires an even greater reliance than hitherto on scientifically based systems of agriculture, if crop quality and farm profitability are to be sustained. For example, optimising the use of fertilisers and pesticides involves stretching them to the limits of effectiveness and specificity, as well as integrating them with biological and other methods of pest and disease control, and with patterns of land use, crop rotation and cultivation designed to conserve nutrients and protect wildlife.

Scientists at the Long Ashton Research Station of the AFRC Institute of Arable Crops Research are undertaking a long-term, farm-scale experiment to study key biological and ecological interactions under different levels of chemical and energy input and with different crop rotations and cultivation practices. This allows the design and evaluation of less intensive arable crop growing in comparison with conventional systems.

Preliminary results from the first two years show that the profitability of conventional systems can be matched in lower input systems which show an overall 35% reduction in production costs and a reduction of 11-21% in machinery costs - with a 7% reduction in yield.

These results show that when integrated with other husbandry practices reduction in levels of nitrogen fertiliser can reduce leaf canopy size in the crop which, in turn, reduces evaporation and water stress, and reduces disease - lowering the requirement for fungicides. At the same time, crop quality and profitability are maintained and nitrate leaching into water may be reduced.

In lower input, integrated systems, significant increases in the populations of major pest predators - spiders, beetles and hover flies - have been recorded over the two years of the experiment. Soil structure has improved in terms of porosity and workability and especially in earthworm biomass - a key indicator of environmental benefit. However, there is also evidence of increased weed populations, and although these are currently containable, more research is needed to prevent potential problems with grass weeds in the longer-term.

This programme is contributing to an EC supported initiative on integrated farming systems research involving partners in Denmark, France, Germany, the Netherlands and Italy.

PROCESS MODELLING TO OPTIMISE FARMING PRACTICES

Farming can be viewed as an engineering process, and process modelling - a mathematical technique - can be used to describe and simulate the influence of each of the many factors that are involved in, and impinge on, farming operations. By combining process models with other information it is possible to identify the most profitable and efficient ways farmers can meet their production and environmental targets.

Comparisons between conventional intensive rotations (winter wheat, winter wheat, winter barley, winter oilseed rape) and low input integrated rotations (winter oilseed rape, winter wheat, winter oats, winter beans, winter wheat) show that profitability can be maintained and environmental benefits achieved at significantly lower levels of input.

One example, developed at the AFRC Silsoe Research Institute, is a model to maximise farm profit under constraints. The farm planning model calculates the most profitable cropping, labour and machinery. The model shows, for example, how one should best adapt to falling crop prices. Major considerations are the annual fixed costs of labour and machinery, the effect of timeliness and rotations on yield, and the workable days expected on different soil types. The model can calculate optimal rates of nitrogen application under different cropping patterns. It can also predict the consequences of an overall "nitrogen quota" on the optimum rate, cropping and farm profits.

Process models quantify the effects and interactions of each of the components of the process. In this case, for example, the model identifies how increased machinery costs to process higher yields influence the optimum rate of N application for different crops. The effects of reduced N use on crop selection, for example, leading to a switch from a grain crop to winter beans can also be identified.

Weed control is another process amenable to modelling. Major considerations in weed management include decisions about: choice of crop, autumn cultivations, timing of planting - autumn, winter or spring crops (i.e. September or November wheat or spring crop) and level of herbicide application. At Silsoe, with funding from MAFF, a model is being developed that incorporates all of these components for controlling major weeds in winter wheat. It takes into consideration the uncertain nature of weather conditions and other factors that might influence herbicide performance.

The model is being constructed in terms of a series of probabilities i.e. it calculates the probability of moving from one state, level of weeds, to another - for each combination of management decisions about crops, cultivations, herbicide etc - over a ten year period. One way in which the model may be used is to identify options for reaching a target end-point i.e. an acceptable level of weeds in 10 years time. From any given starting point, the model maps out the most profitable way of reaching the end-point. Progress can be reviewed annually, allowing changes in management practice if the target path is not achieved. The model also predicts the consequences of external factors such as a fall in crop prices, or imposition of a ban on particular herbicides, and identifies the most profitable ways of compensating for such factors.

This type of approach has been used to analyse the economics of patch spraying, by calculating the savings in herbicide costs that might be achieved using a patch sprayer, as opposed to conventional whole-field spraying, for different levels of weeds, and balancing these against associated equipment costs.

In the long-term, individual farmers may construct their own computer models for process control of farm inputs; these could be adapted for their specific crop requirements, soil and weather conditions. To be useful, such models must be able to handle the complex interactions to provide the information that farmers need to make their management decisions - and profitability is obviously a crucial component. At present there is no easy way to ascribe a financial value to environmental impact. But it is likely that this will play an increasingly important role in the future. Systems modelling will provide ways of estimating and optimising farm profitability by incorporating economic information into process models.

MODELS OF GRAZING AND PLANT GROWTH

If sheep graze a pasture of white clover and ryegrass, will they maintain a balanced mixture of the two species, or drive one of them to extinction? The answer to this question, of great importance to farmers using the clover-ryegrass mixture, depends on two sets of factors. First, the response of the plant species to defoliation, and second, the preferences of the grazing sheep. An AFRC link programme between the AFRC Institute of Grassland and Environmental Research, North Wyke and the AFRC Unit of Ecology and Behaviour at Oxford, brings together IGER's expertise in plant physiology and population biology with Oxford's experience in mathematical modelling of behavioural processes. The objective of the work is to develop and test an optimal control model of sheep grazing, and to link this model with IGER's model of plant growth under grazing.

The model of sheep grazing is being evaluated in field experiments in which the behaviour of sheep is monitored continuously over several days. These experiments have already supported some non-intuitive predictions of the grazing model, for example that the proportion of clover in the sheep's diet should vary in a predictable way with time of day, hunger level of the sheep and availability of clover in the sward.

An experiment to test the response of sheep to spatial heterogeneity. The sheep are foraging on "patches" of sheep pellets in plastic bowls. The results of this experiment are used to generate mathematical models of how sheep graze in ryegrass-clover swards.

Current work is extending the model and experiments to include an analysis of spatial heterogeneity. Clover-ryegrass swards are always spatially heterogeneous: in some parts of the field there are patches of clover, in other parts, grass predominates. How do these heterogeneities arise? How do sheep respond to them? What effect do they have on the overall balance of species in the sward?

Although this collaboration focuses on sheep-ryegrass-clover interactions, the techniques and models will be general in their application and therefore be of value in predicting the consequences of grazing in other systems, including florally diverse pastures generated by extensification.

The amount of clover in a sward is determined by its response to environmental factors and its complex interactions with the companion grass, grazing animal and *Rhizobium* bacterium. Research at IGER, Aberystwyth is defining the disparate characters which control yield and persistency of white clover and its responses to biotic and environmental factors. These characters are used to develop selection criteria and ultimately new improved varieties. Potential varieties are assessed under realistic managements and in the official testing system with funding from the commercial partners, Germinal Holdings, who have met "near-market" costs of the programme since 1988 under a contractual funding and marketing arrangement. Current breeding objectives include improvement in yield and reliability; yield and persistency under intensive grazing; and N fixation and total mixture yield.

NEW OPTIONS FOR CROP PROTECTION

Enzyme alternative to spraying potatoes?

Potatoes face attack from a wide array of bacteria and fungi. Among those inflicting the greatest damage commercially are the bacteria *(Erwinia carotovora)* which cause blackleg and soft rot of tubers, and fungi such as *Fusarium* which cause dry rot, and *Verticillium dahliae*, the causative organism of verticillium wilt. Protection of potato crops relies heavily on chemical sprays, but AFRC supported research by the Plant Molecular Biology Group at the University of Durham, is exploring an alternative approach - the introduction into potato plants of the enzyme lysozyme, one of nature's own bacteriocides and fungicides.

Lysozyme is a relatively small enzyme, its amino acid sequence, three-dimensional structure and mode of action are well characterised. Lysozyme effectively cleaves the polysaccharide components of bacterial cell walls and it is also able to break the linkages between the subunits of chitin which is a major component of fungal cell walls. Its action weakens the cell walls of the microorganisms and tests carried out by the Durham group show that the enzyme significantly inhibits the growth and spread of the microorganisms.

A particularly rich source of lysozyme is hen egg-white and it is the gene encoding this enzyme which is being used initially by the Durham researchers. Their strategy is to use the genetic material (DNA) specifying hen egg-white lysozyme, to engineer it so that it is synthesised within the tissues of potato plants and then to test the effectiveness in protecting the plants against attack by bacteria and fungi.

Transgenic potato plants containing the lysozyme gene have been produced and shown to be synthesising egg-white lysozyme throughout the plants. Particularly important is the demonstration that the enzyme is synthesised to a high level within the tubers. Preliminary tests have indicated that the plants do have enhanced resistance to bacterial pathogens. The transgenic plants are now undergoing containment glasshouse, pathogen-resistance trials in a collaboration with the SOAFD-funded Scottish Crop Research Institute (SCRI). Future work will involve the use of a totally synthetic gene encoding a lysozyme-like enzyme with increased efficiency towards potato pathogens and full field trials at SCRI.

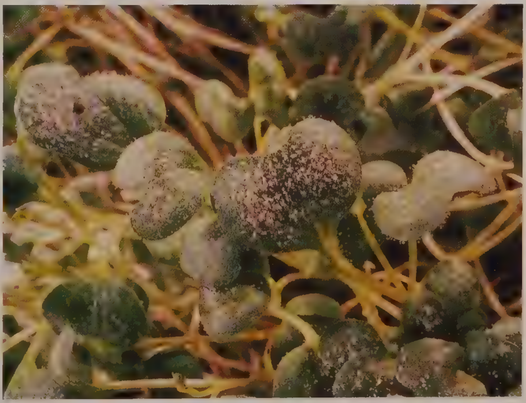
Disease resistance genes in Arabidopsis thaliana

The central tenet underlying the worldwide effort to map the genome of *Arabidopsis thaliana* is that knowledge about the location and organisation of genes in this simple weed will allow rapid identification, and hence exploitation and manipulation, of corresponding genes in commercially important crops. AFRC is playing a major role in *Arabidopsis* mapping. In the search for genes that protect against attack by pests and diseases there is optimism that the weed's genes will be directly relevant to crop improvement in brassicas.

Circumstantial evidence that wild populations of *Arabidopsis* differ in their ability to withstand natural attack by fungal pathogens led scientists at Horticulture Research International (HRI) to explore the genetic basis of resistance. They found patterns of response consistent with a gene-for-gene recognition process between resistance (R) genes in the plant and matching genes, called avirulence genes, in the fungi.

The fungi, *Peronospora parasitica* which causes downy mildew and *Albugo candida* which causes white blister, are important pathogens of cultivated brassicas. Systemic infections of some types of oilseed brassica by both fungi can drastically reduce yield through hormonal disturbances that result in malformations of floral parts.
In horticultural brassicas, the quality of the marketable product can be severely reduced by both local and systemic infections.

When HRI scientists examined the response of different accessions of *A. thaliana* to inoculation with two isolates or races of *P. parasitica*, they found that about half were resistant to both isolates, and about 18% were susceptible to both. The remainder were resistant only to one or other isolate. Subsequent tests with several additional isolates led to the development of a hypothetical gene-for-gene model. The model which is still being validated currently suggests the



Sporulation of Peronospora parasitica (downy mildew) on cotyledons of Brassica
(photo: University of Nottingham).

Typical Malaysian terraced vegetable farm where infestation with diamondback moth can make the entire crop unsaleable.

existence of eight different R genes and their matching avirulence genes. Each R gene conditions a characteristic resistance response and is effective against a unique spectrum of isolates. Isolate specific resistance to *A. candida* has also been located in some accessions.

In collaboration between scientists at HRI and Wye College, molecular mapping techniques are being used to determine the location of resistance genes in the *Arabidopsis* genome and identify fragments of DNA carrying them. It might be possible to generate transgenic brassicas carrying *Arabidopsis* genes to provide resistance to white blister and downy mildew.

Other approaches for isolating R genes are described on pages 10-11.

Pheromone lure for hop aphids

Chemicals that trigger behavioural responses are part of the natural communications system of insects. Their roles include, for example, the establishment of social hierarchies and "alarm" warnings to elicit dispersal. These semiochemicals provide biologists with natural agents for controlling pest behaviour. Of particular interest are the pheromones that are involved in mating: their exploitation allows interference at this crucial stage in the life cycle.

Scientists at the AFRC Institute of Arable Crops Research at Rothamsted, in collaboration with Horticulture Research International at East Malling, are the first to have fully characterised a sex pheromone from aphids. They have shown that a synthetic form of the compound (known chemically as a nepetalactol but as two specific isomers) is biologically active and can be used to lure aphids into traps.

The pheromone that has been characterised is produced prior to egg-laying by females of the damson-hop aphid. This pest infests hops during June-September where it reproduces asexually. As autumn approaches, autumn migrant females fly to *Prunus* (mainly blackthorn and plum) where they produce sexual females which mate and lay eggs. The pheromone attracts males, which migrate from the hop shortly after the migrant females.

In field trials, very large numbers of male aphids (and, surprisingly, some autumn migrant females) were attracted to traps "baited" with the synthetic pheromone. Such traps might be used in crop protection simply to immobilise aphids or they could contain a pathogen which the captives would pick up and subsequently spread to other aphids on their escape. This research is continuing in collaboration with a commercial company that has expertise in the synthesis and formulation of pheromones. In addition, the molecular biology associated with the biosynthesis of the pheromone is under investigation, facilitated by the presence of a related pathway in the labiate *Nepeta racemosa*.

Fungal control of diamondback moth in S E Asia

Fungi that are parasitic on insects are attractive biological control agents for two reasons. Many are specific, allowing pest species to be targeted without harming beneficial insects. Secondly, fungi attack by mechanical means and through a cocktail of enzymes - making it virtually impossible for insects to evolve an effective resistance, unlike the situation with chemical agents.

Scientists at the AFRC Institute of Arable Crops Research at Rothamsted have investigated how one fungus, *Zoophthora radicans*, might be exploited to control diamondback moth, *Plutella xylostella*.

Plutella is a serious pest of brassicas in South East Asia and Latin America where these are grown year-round, and the pest moves from crop to crop without a "closed" season. In parts of Malaysia, for example, sprays are applied up to three times a week; as a result pesticide-resistance has increased to unmanageable levels.

With funding from Shell Research, Rothamsted scientists have shown that highly virulent strains of *Z. radicans* are effectively transmitted within populations of *Plutella* and so might be used in control programmes. This fungus exists naturally in many of the areas affected by *Plutella* but its presence is intermittent and localised.

In an initial field trial in Norfolk, application of the fungus to the leaves of Brussels sprouts resulted in a 70% kill after 10 days. Subsequent laboratory tests have confirmed that traps containing fungal spores, and baited with a pheromone to attract adult male months, are a potentially effective and cheaper alternative to leaf treatment.

The trap system gave encouraging results in a trial in Malaysia using field-sized cages. The next stage will be to go to full-scale field trials, for which the Rothamsted team is seeking sponsorship when the Shell Research funding ends in Autumn 1992.

Exploiting the chemistry of natural insecticides

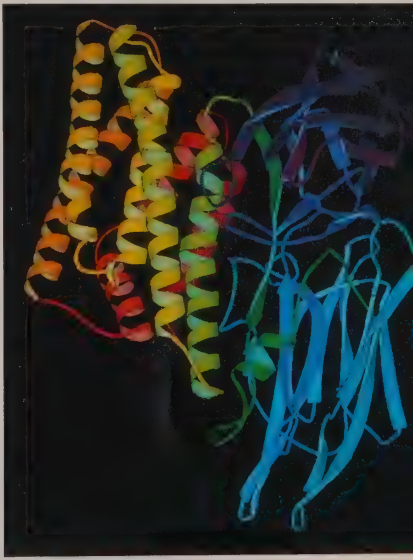
The bacterium *Bacillus thuringiensis* makes its own insecticides. Indeed, it is quite a sophisticated chemical factory: different subspecies producing different protein toxins active against specific orders of insects: moths, beetles, flies, etc. These toxins have been formulated into commercial insecticides for many years.

AFRC supported scientists at the University of Cambridge are the first to have resolved the molecular structure of one of these natural pesticides - the beetle toxin from *B. thuringiensis tenebrionis.* By comparing this structure and its amino acid sequence with the sequences of toxins from other subspecies, and by studying how targeted modifications to these sequences affect the properties of the toxins, it should be possible to identify how these toxins work and what determines their specificity. This, in turn, will suggest strategies for improving potency and specificity. For example, it might be possible to extend the host range of insecticides so that they kill a wider range of pests, whilst remaining non-toxic to beneficial insects such as the natural predators of pests.

The *B. thuringiensis* toxins are synthesised in inactive forms (δ-endotoxins) in the cytoplasm of the bacterial cell. They are released as water-insoluble crystals when the bacterium sporulates. When ingested by a susceptible larva, the crystals are solubilised, and proteases in the gut, together with the alkaline pH, activate the toxins. These create leakage channels in the membranes of the cells lining the gut, killing the larva.

The beetle toxin is a wedge shaped molecule with three main domains (compact regions joined by more flexible links). These are a bundle of seven helices (I); and two regions of sheet assemblies (II and III) (see diagram). The amino acid sequences that make up the core of the molecule encompassing the interfaces of the three domains are very similar in all the *B. thuringiensis* toxins, so it is likely that they adopt the same general fold as the beetle toxin.

The host specificity of a toxin is thought to be determined by sequences in domain II which recognise and bind to specific receptors in the membranes of the gut cells. The structure of the beetle toxin also gives clues about how the toxin can insert itself into the cell membrane, causing the leakage channels that ultimately kill the larva. The long helices of domain I are amphipathic, i.e. one side has affinity for aqueous environments and the other for hydrophobic environments. It is thought that conformational changes upon binding to the membrane cause the helices to align their hydrophobic (water-hating) surfaces with the lipids inside the membrane - thus effectively inserting the molecule into the membrane and making a channel or pore. Thus, as well as their relevance to improved pest control, the mechanisms of toxin behaviour could provide insights into a wide range of gut-perforating toxins implicated in plant and animal pathogenesis and food poisoning.



The molecular structure of a natural pesticide - the beetle toxin from B. thuringiensis tenebrionis. *The polypeptide pathway is indicated by colouring the chain in rainbow order from red at the N terminus to blue at the C terminus.*

EXPERT SYSTEMS AID WASTE MANAGEMENT ACROSS EUROPE

Pollution by waste from intensively reared livestock can be prevented using modern technology and management systems. Unfortunately, the detailed information needed to design efficient and environmentally friendly systems is often not easily obtained by the farmers and advisers who must make everyday decisions about waste management, and tackle potential pollution problems.

Now, however, expert technical advice on the handling, treatment and disposal of pig slurry, so as to control odours and prevent water pollution is readily available - from a computer. The system, known as WEES (Waste Engineering Expert System) has been developed at the AFRC Silsoe Research Institute under contract with ADAS. Meanwhile, with joint funding from ADAS and the EC, Silsoe researchers are coordinating a five nation project to develop a European version of WEES. This will include other livestock species and will provide technical, managerial, economic and legislative information across the Community.

WEES and its European counterpart (EWEES) are members of the growing family of expert systems used in agriculture. These handle real problems using a computer model of logical reasoning to arrive at the same conclusion that would be reached by a human expert. For the user, expert systems provide an instant expert "on call" in the computer.

The challenge for knowledge engineers at Silsoe is to identify the components of a problem, and to collect and organise all relevant information, including costings, available for its solution. Their end product is a menu-driven program that communicates in plain language, and which can be used by farmers or advisers with little specialist knowledge.

The development of WEES and EWEES draws heavily upon the research expertise at Silsoe, augmented by other research experience at the AFRC Institute of Grassland and Environmental Research, and by the advisory expertise of ADAS. WEES deals with topics such as odour prevention, avoidance of water pollution, aerobic treatment of slurry and the design of slurry handling and storage systems. Because the selection and design of waste treatment processes requires a combination of qualitative and quantitative approaches, WEES operates in stages. Initially the user is asked about the problem so that main constraints and requirements are identified. A system of rules is used to select the technical approaches most suitable and these are then analysed in detail and costed.

Other knowledge-based systems under development at Silsoe are working towards the fully automated control of environmental conditions inside greenhouses - supported jointly by the DTI and commercial and industrial sponsors; and the management of soilless culture techniques for greenhouse crops - for which support is being sought from the Horticulture Development Council.

In collaboration with ADAS and EC partners, waste management systems are being designed that protect the rural environment.

NATIVE SPECIES IN THE AGRICULTURAL LANDSCAPE

Populations of native plants and animals in agricultural environments often exist as networks of patches, within which population density is high, connected by areas of low population. This population structure is imposed by the patchwork nature of the agricultural landscapes: from the point of view of any particular species, the landscape consists of islands of suitable habitat (e.g. woodland) surrounded by a sea of inhospitable environment (e.g. arable fields and pasture). Understanding the dynamics of patchily distributed populations, so-called metapopulations, has important implications for agriculture, whether from the need to elucidate the causes of pest outbreaks or from the desire to conserve endangered native populations.

At Oxford University, the AFRC Unit of Ecology and Behaviour is using a combination of mathematical modelling, detailed field studies of particular focal species and molecular biology to increase our understanding of metapopulations in agricultural environments.

By examining the equilibrium properties of mathematical population models it is possible to evaluate the potential consequences of changes in land use for metapopulation persistence. What, for example, is the likely effect of removal of individual habitat patches on the persistence of a metapopulation as a whole? The aim of such models is to gain a feel for the kinds of properties of a population that will render it more or less vulnerable to habitat loss. In one model, for example, loss of habitat patches favours species that are good at dispersing although weak competitors: characteristics shared by many weed species.

The hedgehog is providing valuable information about the factors that influence population dynamics of native species in agricultural environments.

One of the difficulties of applying the theory to real populations is that it is extremely hard to measure accurately some of the key parameters, such as the movement of individuals between patches. Imagine the difficulty of tracking individual aphids to discover how, on average, they move within a generation! Here, the Unit of Ecology and Behaviour is pioneering the use of techniques of molecular biology to answer ecological questions. By isolating appropriate DNA sequences, it will be possible to develop genetic markers that act as population-specific fingerprints. Using these genetic markers in combination with newly developed mathematical models, it will be possible to measure population movements rapidly and for a range of spatial scales.

The molecular and mathematical techniques are being developed in conjunction with detailed feed studies of particular species, which serve as models for the general principles. One such focal species is the hedgehog, chosen for a variety of practical reasons as well as its interest to conservationists. In this species the molecular analysis of DNA "microsatellites" has shown that hedgehog populations separated by only a few kilometres are genetically distinct. Great variations in local abundance of hedgehogs are caused primarily by variation in the abundance of predators such as badgers.

These studies of metapopulations require interdisciplinary teamwork by mathematical modellers, field ecologists and molecular biologists. The answers they provide will be of widespread importance in understanding the reciprocal relationships between agriculture and native populations.

COLLABORATIVE PROGRAMMES ON ENVIRONMENTAL ISSUES

AFRC's research into the basic biological and ecological mechanisms governing the environmental impact of agriculture and land-use is complemented by participation in collaborative initiatives that encompass wider scientific, industrial and social issues.

Clean technology

Many of the exciting opportunities to develop cleaner technologies depend on a systems approach that brings together relevant expertise in biology and engineering. AFRC and SERC are collaborating to stimulate research in this area. The two Councils jointly established the Clean Technology Unit in 1990, the AFRC support being £5M over five years.

AFRC scientists made major contributions to the first three reports of the Unit, published in January 1992: Clean Synthesis of Effect Chemicals; Farming as an Engineering Process; and Harvesting Photosynthesis. Several examples of AFRC research directed at developing cleaner technologies are described elsewhere in this Report. These include the potential for replacing chemical synthesis of industrial raw materials by modulation of plant metabolism (pp 16-17, 28-29); exploitation of plant biomass as a renewable energy source (pp 26-27); integrated farming systems (pp 32-33); better waste management (pp 38) and biological control systems (pp 36-37).

Some clean technologies based on exploiting plant metabolism will be of particular value in marginal habitats, in harsh climates (particularly developing countries with fragile ecologies) and in dispersed, point-of-use situations. We need to know more about how plants cope with extremes of temperature, nutrient and water supply, and under mechanical stress and pathogen attack.

Scientists at the AFRC Institute of Grassland and Environmental Research are identifying the physiological and genetic mechanisms by which plants respond to environmental changes. Some responses are rapid. For example, leaf growth rate changes immediately and reversibly with changes in temperatures probably through direct effects of temperature on cell wall softening. On the other hand, response to longer-term changes in, for example, cold, drought and nitrogen limitation, generally involves altered patterns of gene expression. At IGER, genes expressed in response to specific environmental triggers are being identified, and their products related to observed changes in plant physiology and metabolism.

Pollutant transport in soils and rocks

The processes and pathways involved in the transfer of pollutants between land

and water are the subject of a £1.2M initiative launched jointly by AFRC and NERC in 1991.

The programme includes projects at the AFRC Institute of Arable Crops Research, the NERC Institute of Hydrology and several HEIs. It addresses major issues of concern regarding pollution of both terrestrial and aquatic environments, including the fate of plant nutrients - notably nitrogen and phosphorus, pesticides, heavy metals, hydrocarbons and other organic substances and colloidal materials including microorganisms. A major objective is to develop quantitative predictive models of pollutant transport that may be used to develop strategies for minimising environmental pollution. These are being obtained by an integrated experimental and mathematical modelling approach.

Research at University College London, supported by AFRC/NERC, is examining how the chemistry of dissolved and solid organic matter, in aquifers and ground water, influences the rates of microbial activity. The results will assist in planning bioremediation programmes designed for *in situ* removal of organic pollutants in aquifers.

A joint AFRC/NERC programme involving field studies and laboratory experiments is providing information about the fate of pollutants in soils and groundwater.

(photo: University College London).

Joint Agriculture and Environment Programme (JAEP)

JAEP is a collaborative programme sponsored by AFRC, ESRC and NERC. It started in 1990, with an annual budget of £1.8M. A total of 35 projects is supported in three elements: herbivore and plant interactions; farmland ecology; and changing farm economies.

AFRC sponsors six projects within the first element (see, for example, page 34). In addition AFRC scientists contribute to parts of the farmland ecology element that is led by NERC. For example, at the AFRC Institute of Arable Crops Research, farmland experiments are exploring the movement and seasonal distribution of predator and parasite species that attack aphids. Particular attention is being paid to the way these natural enemies move between semi-natural habitats and farmland crops. A better understanding of the spatial population dynamics of these species will aid the design of sustainable farming systems that seek to make the best possible use of natural predators to control pests.

IMPROVING ANIMAL HEALTH AND WELFARE

Good health is a principal criterion of animal welfare; and health and wider welfare issues often need to be considered together. The health of intensively housed livestock is one such area, and is important economically.

Respiratory diseases in pigs

There is increasing epidemiological evidence linking respiratory disease in intensively housed pigs with aerial pollutants such as dusts and ammonia. These diseases are estimated to cost the UK pig industry over £20M *per annum* mainly through reduced weight gain. For the future, approaches to controlling these respiratory diseases are likely to depend increasingly on environmental and biological control methods, with a reduction in the use of antibiotics.

Collaborative research between the University of Bristol, School of Veterinary Science, the Welfare Science Division of the AFRC Silsoe Research Institute and the AFRC Institute for Animal Health, is aimed at analysing the relationships between infectious diseases of the respiratory tract and intensively managed housing so that building design and management might be improved, thereby decreasing the incidence and severity of respiratory diseases. To achieve this involves understanding more about the aetiology of the diseases, and how pollutants might predispose animals to infection, as well as a better understanding of the dynamics of the generation and clearance of aerial pollutants.

The role of environmental factors such as air speed, temperature and relative humidity is being identified using specially designed experimental building sections at Silsoe and at the AFRC Institute of Animal Physiology and Genetics Research. Computational fluid dynamics (see pages 14 to 15) is among the techniques being used to model air movement in livestock buildings so that predictive computer models may be developed. This research will help to identify tolerance limits for the major pollutants i.e. levels that do not increase susceptibility to disease, and that might therefore be used in recommendations to ensure that building design and operation meets the animals' requirements for good air hygiene.

One disease being studied as part of the search for clues about the role of environmental factors is atrophic rhinitis. In this infectious disease of growing pigs there is erosion of the turbinate bones in the snout. These bones support the large cilia-covered internal surface area of the nose important in filtering and warming incoming air, so their degradation in atrophic rhinitis is of considerable welfare significance - pigs unable to filter and warm the air they breathe must suffer some distress. There is also evidence of reduced weight gain in pigs suffering from atrophic rhinitis - and the disease can hinder herd movement and export.

Studies at IAH and elsewhere have indicated that two organisms are involved: colonisation with *Bordetella bronchiseptica* predisposes the animal to enhanced colonisation by *Pasteurella multocida* - the former causing a reversible atrophy of the turbinate bones, with the latter causing their progressive and irreversible degeneration. It may be that aerial pollutants such as dusts also predispose the animal to colonisation by these pathogens. However, some recent evidence suggests that the syndrome can appear without involvement of *P. multocida*, and this suggests an important role for other organisms and possibly environmental conditions.

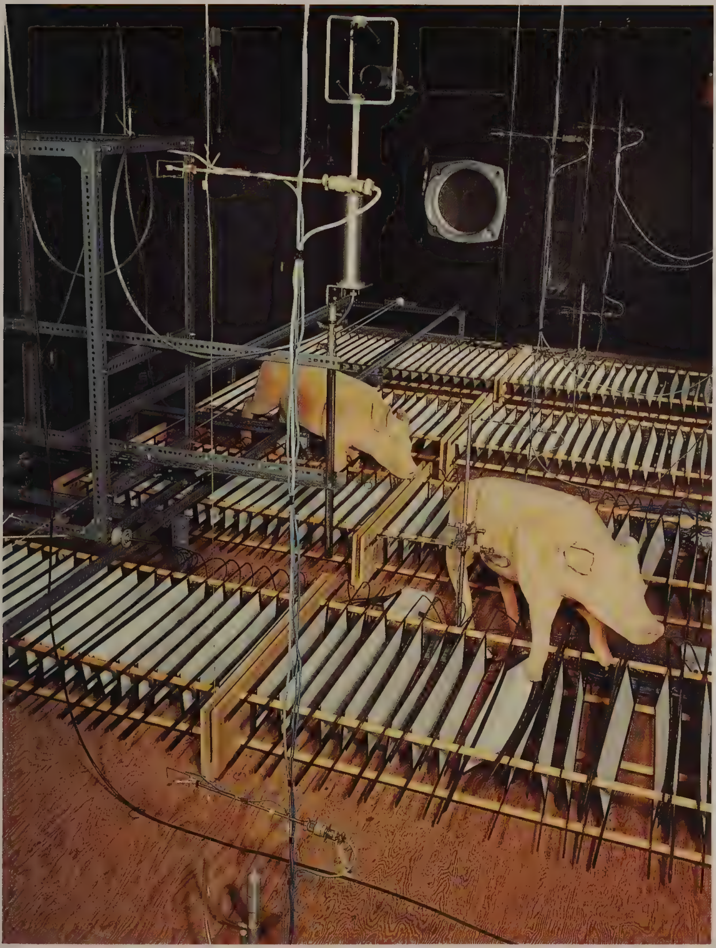
As well as the work on intensively housed pigs, the Bristol and Silsoe groups are collaborating on a study of the natural history of air hygiene in a pullet house, and the effects of internal air filtration on the health and performance of birds.

NEW RESEARCH INITIATIVE ON ANIMAL WELFARE

In 1991 AFRC announced a new coordinated programme aimed at developing a better understanding of the fundamental biology underpinning animal welfare. Improving the welfare of farmed animals is a major AFRC priority. Progress towards this goal requires an increase in the understanding of an animal's perception of its own welfare based on fundamental research in disciplines such as ethology, psychology and neurobiology, both with farm animals and, where appropriate, other species. The science of welfare attempts to measure the physiological and mental state of healthy animals and the changes that occur during stress and disease. The new initiative is focusing on:

- *fundamental investigations of the development of cognition, e.g. awareness plus expectation*
- *studies on the motivation of animals towards specific goals and on the physiological, pharmacological and ethological aspects associated with pathological conditions.*

New projects are being coordinated within AFRC's existing programme which is being carried out at HEIs and in AFRS institutes.



These model pigs show the scale of the ultrasonic anemometer as used in the Silsoe Building Section - an experimental facility used to study turbulence in air flow, an important factor in the movement of aerosols in livestock buildings.

EC STUDY TO REDUCE AERIAL EMISSIONS FROM LIVESTOCK BUILDINGS

AFRC scientists are participating in a four year project funded by the EC to identify ways of reducing aerial pollution from intensive livestock buildings. With partners in Germany, Denmark and The Netherlands, scientists at the AFRC Silsoe Research Institute are gathering data on pollutant emissions from forty eight buildings (four of each of twelve basic designs) in use on commercial farms in each country. These will be used to develop models of the effects on environmental pollution of climatic factors such as temperature and humidity, and of ammonia, methane and dust levels in the buildings, and of building design and operation.

Towards a molecular understanding of how diseases spread

Lethal avian influenza occurs only infrequently in commercial poultry flocks around the world and very rarely in the UK. But when it does occur its severity can be devastating - in 1979 and 1991, for example, outbreaks in the UK killed thousands of turkeys on affected farms but fortunately, in outbreaks in Great Britain there has been very little spread of infection. In 1983 an outbreak in chickens in Pennsylvania and surrounding states in the USA resulted in the death of over 20,000,000 chickens, and the cost to the farmer, government and consumer has been estimated to exceed $300,000,000.

Scientists at the AFRC Institute for Animal Health are studying the replication and assembly of the virus responsible for avian influenza to determine how the virus is spread and how it is able to move from one species to another, including transfer to humans. In collaboration with the Central Veterinary Laboratory (CVL), Weybridge, they have developed a rapid "fingerprinting" technique for virus "pathogenic potential" for domestic fowl.

There is no simple answer to the question "where does avian influenza come from?" Wild species of waterfowl appear to be a major reservoir for the virus.

The epidemiology of avian influenza can be related to the flight paths of these birds - for example, outbreaks in extensively farmed turkeys in Norfolk in 1979 and 1991 could be correlated with the presence in the vicinity of migratory waterfowl, and partial nucleotide sequence analysis of viruses isolated from the outbreaks of 1979 and 1991 showed that they were most closely related to viruses originating from the area of the Volga delta in the Asian/European border.

The frequent isolation of influenza viruses from migratory water fowl and other migratory birds such as terns and gulls indicates a natural reservoir of these viruses. Although it is not possible to state categorically the sequence of passage from one species to another, the likelihood that the virus can spread from migrants to native species and commercial flocks seems compelling, together with its implications for livestock health. It might be that moves towards less intensive methods of poultry farming could increase risks of infection.

Avian influenza virus can change its host range, for example in 1989 an influenza virus from ducks infected horses. It is also able to adapt to enter pigs and thence possibly pass on to man. This has meant that outbreaks of swine 'flu can occur in man, and the episode which occurred in the USA in 1976 elicited a massive human vaccination scheme. A key characteristic that allows this mobility is the fragmented nature of the virus genome. The RNA genome is made up of eight segments. When the virus replicates, each new particle has to package these eight segments. Until recently it was unclear whether packaging is random or segment-specific. Research at IAH is showing that packaging is segment-specific, indicating a regulated packaging in sequence.

This breakthrough in understanding how the virus assembles is directly relevant to understanding the epidemiology of avian influenza. Individual segments may be transferred between viruses allowing the disease to enter a new host species.

The viral gene coding for the haemagglutinin (HA) is the subject of particular interest. Mutations in this gene appear to be important in turning non-pathogenic avian strains into pathogenic strains. A particular region of the haemagglutinin protein is critical in determining pathogenicity in poultry. Scientists at IAH and CVL have developed a rapid method for sequencing the critical portion of the HA gene. They have successfully applied this technique to screen the pathogenic potential of strains of avian influenza virus isolated from 1902 until the end of 1991.

POULTRY WELFARE

Understanding how animals respond to their environment, and how, in turn, environmental factors affect animals' neurophysiology and behaviour are key components of AFRC's programme on animal welfare. As part of this research, the space and environmental requirements of poultry are being identified by scientists at the AFRC Institute of Animal Physiology and Genetics Research. This includes analysis of the effects of flock size on the extent to which birds move around and make use of available space. This research will aid the design of housing and husbandry systems based on welfare considerations.

MEETING DIETARY AND OTHER *consumer needs*

In AFRC, we are using a multidisciplinary approach to address issues of diet and health.

- *We are becoming able to identify molecular events associated with the body's ability to digest foods and absorb nutrients.*
- *In collaboration with clinical researchers we are exploring the role of diet in relation to the prevention of diseases such as colo-rectal cancers.*
- *Our survey work on the relationship between consumer attitudes and patterns of food intake is providing information useful for the drafting of effective dietary guidelines.*
- *We are using biological recognition processes to design rapid diagnostic tests for monitoring the functional quality and nutritional characteristics of foods.*

NUTRIENTS AND GENES

It is implicit in sustainable systems of agriculture and food production that the foods produced are nutritious, not detrimental to human health, and that they satisfy consumer demands. To meet these requirements as fully as possible, we need to know more about how nutrients are absorbed, and also about the mechanisms responsible for pathological conditions associated with diet. "Nutrients and genes" is a shorthand way to describe a particular type of research now being exploited to increase our understanding of how food-gut interactions take place at the cellular and molecular level. This information may then be used in the development of nutritional guidelines in the future.

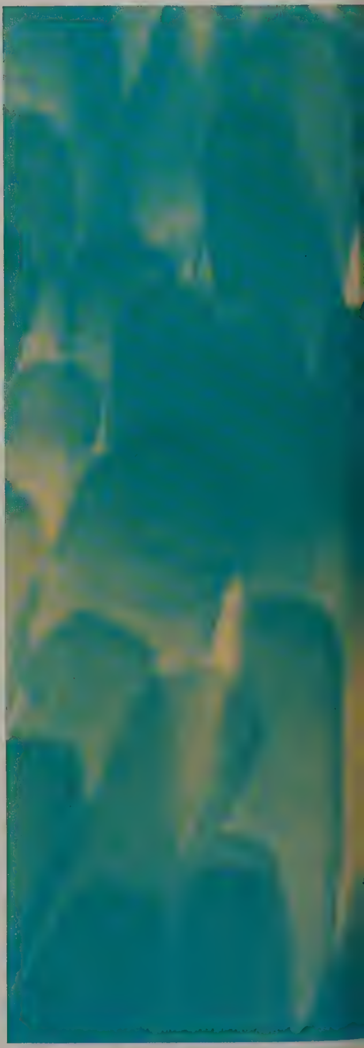
Nutrients are absorbed by the epithelial cells that line the small intestine. These cells produce digestive enzymes to breakdown complex molecules on their surface, and later absorb sugars, amino acids and other important micronutrients. Scientists at the AFRC Institute of Animal Physiology and Genetics Research at Cambridge are investigating how these digestive and absorptive capabilities are influenced by diet.

In simple terms, the cells can adapt to their nutritional environment, allowing optimal use to be made of available resources. Adaptation is achieved through continuous replacement of the epithelial cells on a 2-4 day cycle. If the body detects large amounts of sugar, for example, in the diet, subsequent "generations" of cells have increased ability to absorb it. The IAPGR scientists have developed a battery of powerful techniques that allow them to observe and quantify the molecular changes that eventually allow the cells to digest, absorb and metabolise nutrients.

Gut epithelial cells are "born", without absorptive function, in the crypts at the base of villi - the finger-like projections that protrude into the lumen of the small intestine. They acquire digestive and absorptive properties as they migrate towards the tips of the villi. Using refined techniques of microscopy together with molecular probes and labels, the IAPGR researchers can now identify the timing and sequence of events such as the switching on of a particular gene or synthesis of an enzyme as cells make their journey along the villi. This can then be related to digestive and absorptive function. For example, glucose uptake has been studied in rabbit cells. *In situ* hybridisation using a nucleotide probe derived from the gene for a protein that transports glucose showed that the message (mRNA) for that transporter is present while cells are still near the base of the villi. But there then follows a delay of over thirty hours before glucose transport activity can be detected at the tip. Antibody labelling shows that in the meantime the transporter protein is present and able to bind sugars, but that its activity is somehow repressed.

Similar strategies have been used to study mechanisms controlling lactase synthesis in rat tissue and calcium transport in the small intestine of chickens. Decrease in lactase activity in older animals is not always associated with a parallel fall in mRNA and calcium transport in chicken intestine does not show the expected correlation with an mRNA coding for a vitamin D inducible calcium binding protein. All these studies reveal the complex way in which intestinal cells coordinate sequential gene expression during development and when making adaptive responses to change of diet.

From a long-established base in animal tissue studies, the IAPGR programme is now being applied to samples of human biopsies. Using the same quantitative techniques it should be possible to identify the effects of dietary change on the timing,



pattern and intensity of differentiation in gut epithelial cells. The influence of hormones is also being investigated.

Insulin and gene activity

Insulin is the hormone that signals the "fed" state and stimulates the storage of fuels including glycogen and lipids. Research at the University of Erlangen, Germany, now being continued at the AFRC Institute of Food Research, has indicated how dietary factors, mediated by insulin, influence activity of the enzyme FAS (fatty acid synthase) important in lipid biosynthesis. Molecular dissection of the FAS gene has already identified one portion of DNA involved in switching on the FAS gene during an "insulin response". It is planned to work backwards from this regulator to identify each intermediary step in the signalling process that begins with insulin interacting with a receptor at the outside of the cell membrane. This should provide a full picture of how diet induced changes in insulin levels are translated into changes in the biosynthesis of storage lipid.

The initial work was conducted using rat tissue - in simple terms, rats introduced to a fat free, high carbohydrate diet responded by producing greater amounts of messenger RNA for FAS, and by exhibiting higher levels of FAS activity. In diabetic rats a fat free, high carbohydrate diet did not result in increased transcription of the FAS gene and therefore there was no change in FAS activity. At IFR, this work is being taken forward using cell culture systems. One strategy, for example, for identifying triggers that interact with the insulin-switch for FAS is to isolate this switch and attach it to DNA that codes for an easily detectable product (a reporter gene) and investigate what cell constituents turn on the switch. In the longer-term it is planned to modify yeast cells to act as experimental models for identifying the steps in the insulin response.

Finger-like villi lining the small intestine of suckling young animals exhibit lactase activity on their surface to enable digestion of milk. The blue colour allows quantitative evaluation of this activity to be related to the developmental state of the animal.

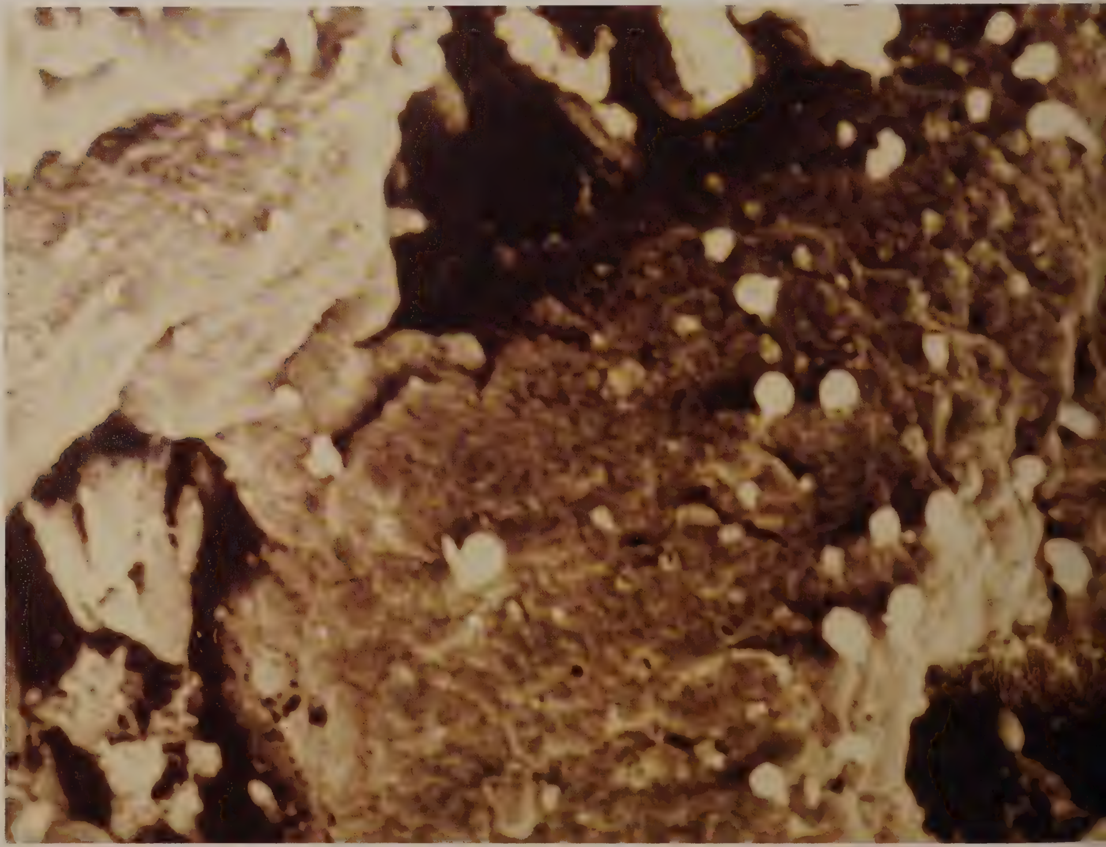
DIET AND HEALTH

There is strong evidence that diet is an important causal factor in human cancers of the large bowel. The first stage in transition from healthy epithelial (mucosal) cells to tumour is believed to involve accelerated cell replication. Highly proliferating cells appear more susceptible to genetic damage, and thus accumulate somatic mutations leading to tumour formation.

Scientists at the AFRC Institute of Food Research are collaborating with clinical researchers to investigate effects of diet on cell proliferation in patients who are screened regularly by biopsy because they show early stages of cell changes that might place them at greater risk of developing colo-rectal tumours.

This is the first step in research aimed, in the long term, at identifying the relationship between diet and genetic changes responsible for tumour development. Mutations are thought to involve both activation of oncogenes and loss of genes which normally suppress emergence of tumours.

An important development has been the design of fast and reliable techniques for measuring cell proliferation rate. The cells proliferate within glandular crypts in the mucosa. In experimental animals the rate of cell division can be estimated by blocking cell proliferation with the drug vincristine and counting the arrested cell divisions. This is not possible in humans, but a new technique has been developed which enables both the rate and location of mitoses to be identified in routine clinical biopsies. In pathological states, the zone of proliferation is enlarged, towards the mucosal surface.



Previous IFR studies on animal tissues indicated that cell proliferation was stimulated by increasing the fat content of the diet. These also provided evidence of positive interactions between fat and other dietary components, notably the viscous, non-starch polysaccharide, guar gum.

The human patients complete semi-quantitative questionnaires designed to assess their intake of fat, dietary fibre and vegetables thought to contain protective factors against colo-rectal cancer. This information is used in conjunction with the biopsy data, and compared with the diagnosis and clinical history of each patient. It may be used to develop optimal diets for these patients.

Using dietary components to prevent bacterial infection of the small intestine is one of several projects at the SOAFD-funded Rowett Research Institute exploring how natural interactions of food-gut-bacteria might be exploited to improve human health.

Lectins are proteins, abundant in plant-derived food, that specifically recognise and bind to sugars in the epithelial lining of the gut. Some are toxic, others are harmless. Researchers at the Rowett are interested in using harmless lectins as probiotics - i.e. to modify the structure and function of the surface of the small intestine so as to protect against harmful bacteria. Bacteria also bind to the gut wall through lectins known as adhesins. Therefore by identifying lectins that are structurally similar to the adhesins of harmful bacteria it might be possible to use them to block potential sites for adhesin binding, effectively swamping out the bacteria and preventing their attachment. Researchers at the Rowett have patented the use of lectins to block proliferation of harmful bacteria in the gut.

Some lectins induce changes in the receptor molecules in the cell walls and so influence the bacterial flora that can attach. In turn, the presence of large numbers of bacteria near the mucosa affects the morphology of the small intestine.

Scanning electron microscopy is used to investigate cell proliferation in the glandular crypts of cells lining the colon - the openings of four crypts are shown here.

Because lectins retain their activity in the gut, by resistance to degradation, they have potential as oral drug delivery systems. Polypeptides such as insulin cannot be taken by mouth because they are digested. However, they could be protected from digestive attack within a lectin complex and, as some lectins can cross the gut wall, their use would allow pharmaceutical agents to be transported into the circulation. The design and the development of such oral lectin-drug-vehicle complexes is actively pursued by the Rowett scientists.

Bacteria and lectins crossing M cells present in the lining of the small intestine initiate a cascade of events leading to the mounting of an immune reaction against antigens. Properly controlled, such a response leads to the eventual export of secretory antibodies into the intestinal lumen where they remove the offending antigens by a process of immune exclusion. Uncontrolled immune responses can on the other hand cause acute inflammation of the gut leading to greatly impaired intestinal function. M cells play an essential role in this case in acting as "gatekeepers" controlling the type and number of antigens transported across the gut lining for presentation to the underlying gut immune system.

Confocal microscopy, fluorescent labelling and electrophysiological studies at the AFRC Institute of Animal Physiology and Genetics Research, provide the first visual evidence in living tissue of how this important interaction takes place in the small intestine. Present research at IAPGR shows that the number as well as the ability of individual M cells to recognise and transport material to the gut associated immune system can be regulated experimentally. These results could have importance for drug targeting as well as in monitoring effects of diet and disease on gut immune function.

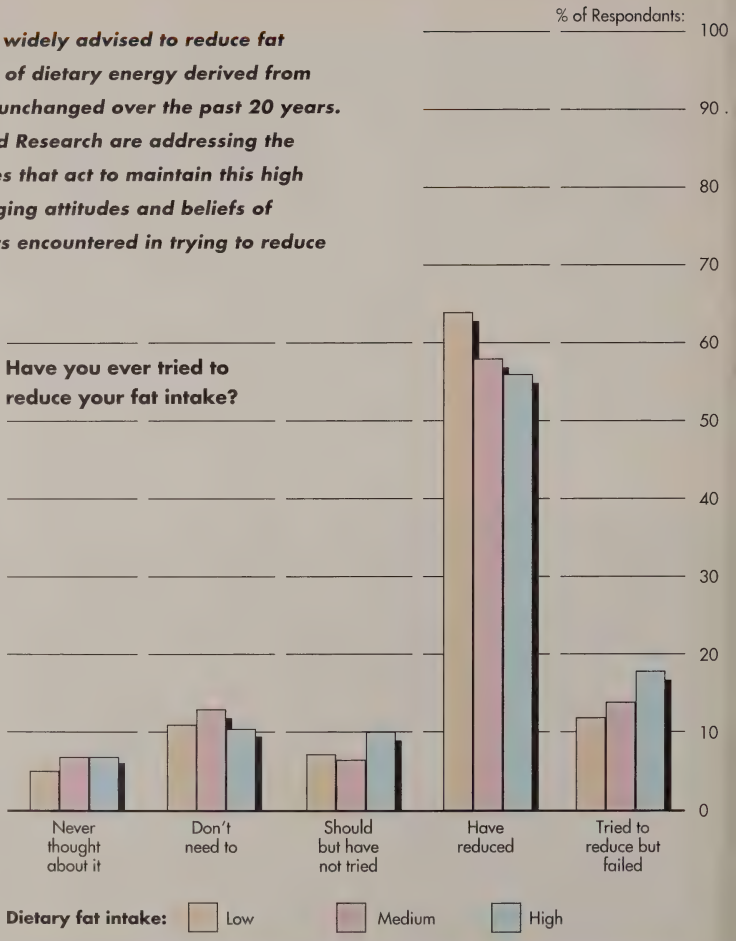
CONSUMER ATTITUDES AND FAT CONSUMPTION

Although consumers have been widely advised to reduce fat consumption, the percentage of dietary energy derived from fat in the UK has remained unchanged over the past 20 years. Scientists at the AFRC Institute of Food Research are addressing the physiological and psychological forces that act to maintain this high intake. They are surveying the changing attitudes and beliefs of consumers, and assessing the barriers encountered in trying to reduce fat intake.

As part of a project supported by MAFF, an IFR survey conducted in 1991 showed that despite consuming high levels of fat, the UK public in general has highly positive attitudes toward reducing fat intakes, with few respondents indicating that they never thought about or did not need to reduce their fat intake. Consumers also have very positive attitudes toward many specific dietary changes intended to meet that objective. However, some people are concerned that making many of the dietary changes to reduce fat intake would impair the taste of their meals.

A major finding from this work was that many UK consumers have a misconception of their own fat intake, judging it to be low relative to its measured level. Most also indicated that they had tried and were maintaining a reduced-fat diet, even most of those found to have a high fat intake. Hence, one major barrier may relate to a general failure to recognise what comprises effective dietary change.

With growing interest in low- and reduced-fat foods, both in industry and the general public, it is critical to assess consumers' response to these products in their diet. IFR research shows that sensory acceptance of reduced-fat foods is a function of interactions between product information (e.g. labels and claims) and consumers' beliefs and attitudes. Current research is examining how use of reduced-fat versions of foods influences overall food selection, acceptance, and intake patterns.


Have you ever tried to reduce your fat intake?

Leaner Meat for Consumers

Selection of pigs for extremely lean carcasses has sometimes been associated with poorer eating quality of the meat. As a result there has been interest in introducing the Duroc breed which has a higher proportion of intramuscular (marbling) fat than other breeds, which may be related to eating quality. Trials at the AFRC Institute of Animal Physiology and Genetics Research at Edinburgh have shown that there is considerable genetic variation in meat quality traits, such that quality can be improved both through direct and indirect selection procedures.

Basic studies on the genetics of protein and fat metabolism in sheep are helping to identify selection criteria to improve carcass composition of sheep, notably by increasing the proportion of lean meat (muscle).

PROBING NUTRITIONAL AND FUNCTIONAL QUALITY OF FOODS

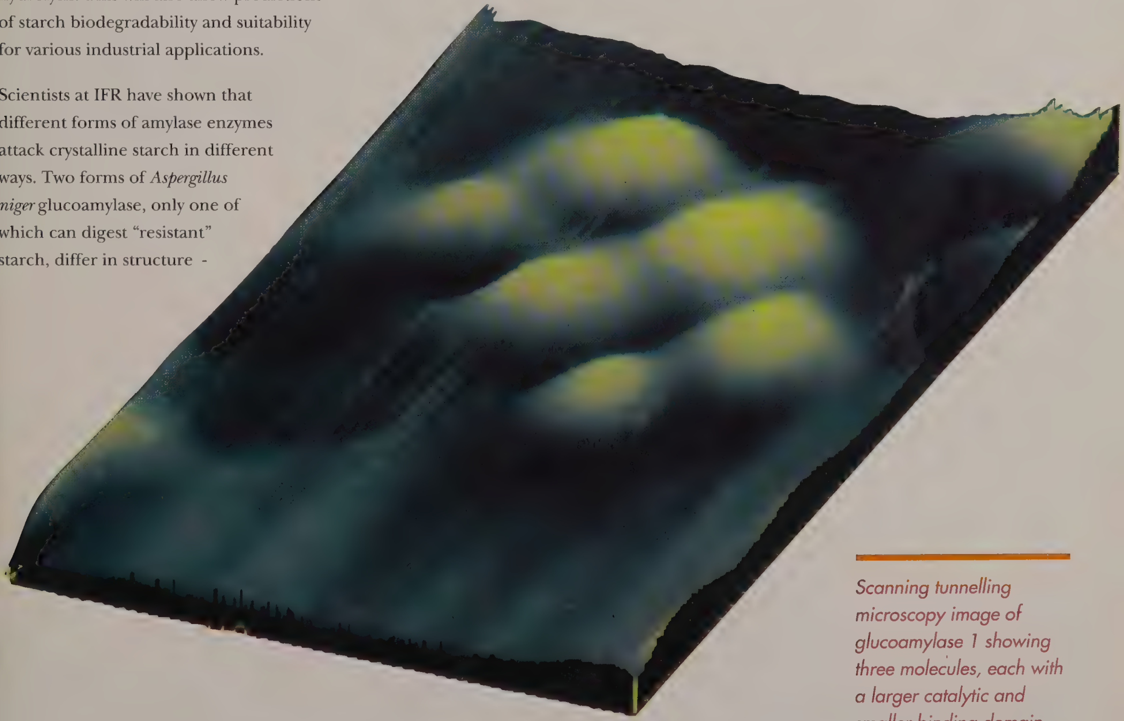
Several projects are aimed at providing rapid and highly sensitive methods for detecting molecular motifs that determine quality attributes of foods. Typically, these methods rely on biological recognition processes e.g. enzyme-substrate and antibody-antigen interactions. At the AFRC Institute of Food Research advances have been made in exploiting enzyme specificities to measure starch digestibility, and in antibody probing of proteins that govern breadmaking quality of flour.

The physical structure of starch determines the extent to which it is either hydrolysed by enzymes in the small intestine or resists hydrolysis and passes into the colon. In order to predict digestibility - for example to provide accurate nutritional labelling of foods - we need to know more about how starch structure influences susceptibility to hydrolysis. This will also allow predictions of starch biodegradability and suitability for various industrial applications.

Scientists at IFR have shown that different forms of amylase enzymes attack crystalline starch in different ways. Two forms of *Aspergillus niger* glucoamylase, only one of which can digest "resistant" starch, differ in structure - that able to digest the starch has an extra domain common to many microbial amylases. This enzyme can be used in studies to correlate starch structure with digestibility, and information (from techniques such as scanning tunnelling microscopy) on the structure of its extra domain is providing clues about how enzymes hydrolyse starch. In the long-term it might be possible to add the domain to other enzymes so equipping them to hydrolyse "resistant" starches.

Some of the fifty or so proteins of flour known as gluten govern the elasticity and extensibility of dough, important in achieving a good foam structure in bread. In developing monoclonal antibodies to probe the components that determine breadmaking quality, researchers at IFR have been the first to show the direct involvement of some low molecular weight proteins in quality. A battery of monoclonals is being established that forms the basis of both quantitative and qualitative assays.

Within the EC's ECLAIR programme, antibodies are also being produced to pentosans - polysaccharides that are also implicated in breadmaking quality.



Scanning tunnelling microscopy image of glucoamylase 1 showing three molecules, each with a larger catalytic and smaller binding domain.

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AND OTHER REPORTS

In AFRC, we are continuing to improve operational efficiency in support of policy objectives.

- *For 1991/92, AFRC's income from the Science Budget was £96.9M. Commissioned research from MAFF amounted to £34.5M. Total external income earned by AFRC supported institutes increased to £20.0M.*
- *AFRC's funding of research in higher education institutions has continued to increase, with a total expenditure of £19.4M in 1991/92, an increase of 23%.*
- *We have sustained and strengthened our commitment to international collaborative research. We are on course to meet our target of £3M income p.a. from the EC for 1992/93. We are exploring with the ODA, and other organisations, how AFRC's research base may be used to benefit sustainable agriculture in developing countries.*
- *We have implemented new initiatives in training and staff development, in performance management and the areas of employee relations and equal opportunities.*

FINANCIAL STATEMENT

For the financial year ending 31 March 1992, the expenditure of the Council and Council owned institutes was ***£141.3M.***

The expenditure was financed from the following sources:

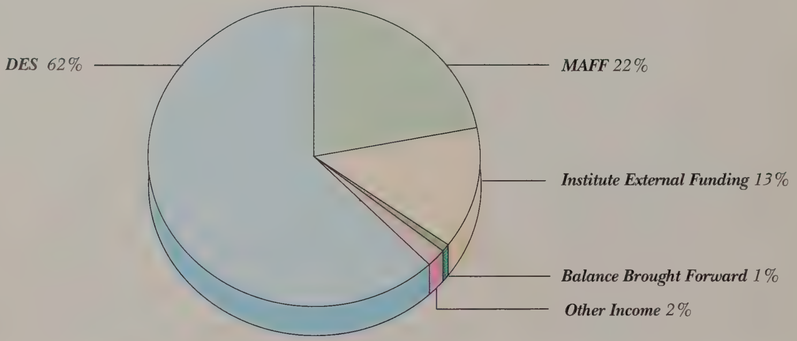
Science Budget grant-in-aid from the Department of Education and Science was ***£96.9M*** (net of capital receipts) and commissioned research from the Ministry of Agriculture, Fisheries and Food amounted to ***£34.5M.***

This major funding was augmented by further Council income totalling ***£9.8M*** being mainly contract and other income from industry and Government organisations and capital receipts. The rest came from miscellaneous sales.

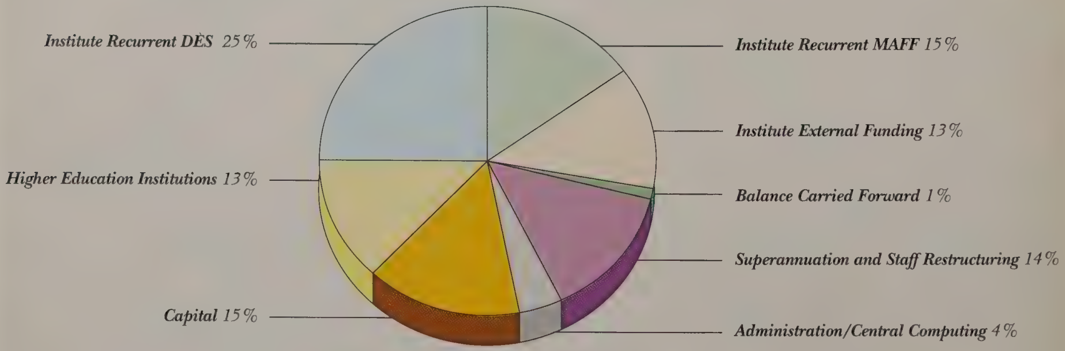
In addition to this income received by the Council, AFRC grant-aided institutes received outside funding estimated at ***£13.8M*** from contracts and other agreements with industry, Government Departments, EC, Foundations and Trusts, etc. This income is included in the table on page 56.

At the year end, the Council held a balance of ***£1.7M***; mainly in respect of capital commitments and commercial contracts.

TOTAL AFRC INCOME FOR 1991/92 INCLUDING EXTERNAL FUNDING OF GRANT-AIDED INSTITUTES (£155.1M)



TOTAL AFRC EXPENDITURE FOR 1991/92 INCLUDING EXTERNAL FUNDING (£155.1M)



SUMMARY OF INCOME AND EXPENDITURE OF THE COUNCIL for year ended 31 March 1992

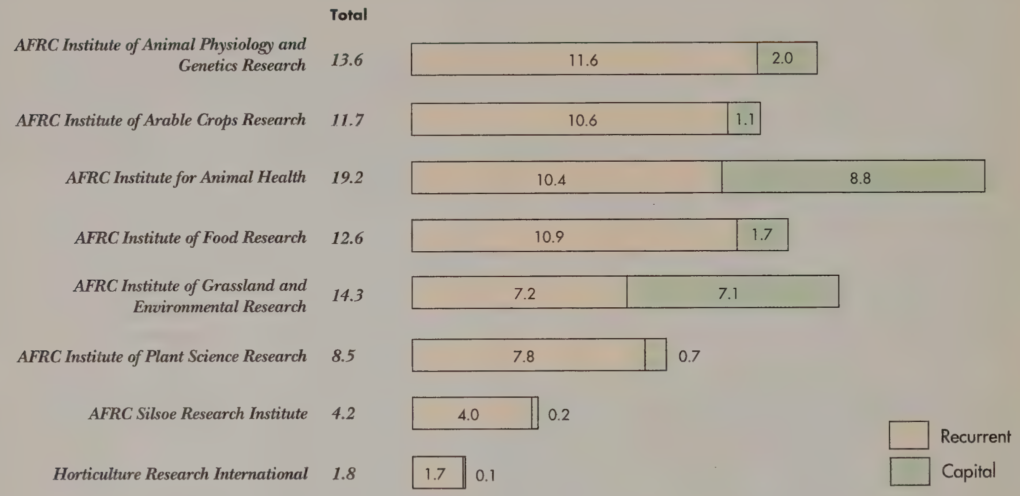
	1990/91		1991/92	
	£K	£K	£K	£K
Income				
Balance brought forward	1,179		1,419	
DES Grant-in-Aid	88,400		95,567	
MAFF Commissions	45,105 †		34,516*	
Council institutes and units	5,692		6,722	
Capital receipts/other income	989		3,109	
Total Income (including balance brought forward)		141,365		141,333
Expenditure				
Recurrent Expenditure				
Council and Grant-aided Institutes	75,045		69,242	
Research Grants to HEIs	14,153		17,112	
Postgraduate Training Awards	1,556		2,263	
Administrative and Central Computing Costs	6,578		6,769	
Superannuation and Staff Restructuring Costs	19,837		21,625	
Total Recurrent Expenditure		117,169		117,011
Capital Expenditure				
Land and Buildings	17,042		18,681	
Capital Equipment	5,735		3,936	
Total Capital Expenditure		22,777		22,617
Balance Carried Forward		1,419		1,705
Total Expenditure (including balance carried forward)		141,365		141,333

† *Excludes £537K paid to AFRC but transferred to the University of Bristol.*

* *The reduction in MAFF Commissions income for 1991/92 mainly reflects the payment by MAFF direct to Horticulture Research International (HRI) following the setting up of HRI as a Non-Departmental Public Body.*

The full Accounts are published as a House of Commons Paper available from Her Majesty's Stationery Office.

Net Cash Grants to Council and Grant-Aided Institutes (£M) 1991/92



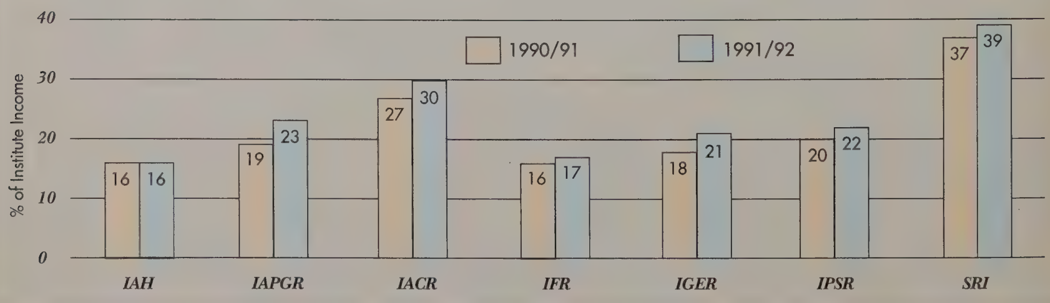
The capital funds for IAH and IGER include allocations for major restructuring.

EXTERNAL INCOME

Income from commercial and other sources: 1991/92

Institute	Industry	Levy	Government Departments	MAFF Ocf	Trusts etc	EC	Total (£K)
IAH	899	0	476	0	161	529	2065
IAPGR	1597	51	1141	242	483	210	3724
IACR	997	1662	1376	210	141	434	4820
IFR	1357	0	249	146	26	596	2373
IGER	882	251	286	374	0	77	1870
IPSR	1111	0	384	48	202	561	2306
SRI	872	87	1431	158	0	317	2865
Total	**7715**	**2051**	**5343**	**1178**	**1013**	**2724**	**20023**

Commercial Income at AFRC Institutes 1990/91 and 1991/92 as % of Institute Income



Exploitation Income

In the 1991/92 financial year, total exploitation income at institutes was in excess of £500K. In the same year BTG (formerly NRDC) earned some £9M gross from the exploitation of pre-1985 AFRC inventions, and cumulative income from AFRC inventions since NRDC was first established is around £106M.

LINK and AFRC collaboration with industry scheme

In 1991/92, AFRC spent £950K on both LINK and its own scheme for collaboration with industry.

AFRC is co-sponsor of eight LINK programmes:

	AFRC commitment (£M)
Control of Plant and Microbial Metabolism	*0.3*
Protein Engineering	*0.5*
Eukaryotic Genetic Engineering	*0.5*
Molecular Sensors	*0.25*
Design of High Speed Machinery	*0.5*
Industrial Use of Crops	*1.0*
Agro-food Quality	*0.5*
Sustainable Farming Systems	*0.45*
Total	**4.00**

Major industrial contractors during 1991/92 included:

Agricultural Genetics Company Ltd
Animal Biotechnology Cambridge Ltd
British Sugar
BP International Ltd
BP Nutrition Ltd
British Technology Group
Ciba-Geigy Agrochemicals
Du Pont (UK) Ltd
Germinal Holdings
ICI plc
Intervet plc
Pitman-Moore
Rhone Poulenc Agrochemie
Semundo Ltd
Sigma Tau Pharmaceuticals
Unilever plc

HEI FUNDING

In 1991/92 AFRC continued with its policy to increase support for research and research training in HEIs. Total expenditure rose by 23% to £19.4M.

- expenditure on research grants schemes increased to £17.1M
- expenditure on postgraduate training awards and fellowships increased to £2.3M
- research studentships totalled 285
- average value of research studentship stipends increased to £5.5K in October 1992 and will increase to £6K in October 1993
- a further 8 AFRC Postdoctoral Fellowships were awarded

In July 1991, the then Secretary of State for Education and Science announced that from August 1992 the Research Councils would be responsible for meeting all the costs of research they support in HEIs apart from academic salaries, and premises costs and central computing costs. Funds would be transferred from the Universities Funding Council to the Research Councils to meet the additional costs to research grants under the new arrangements. The main purpose of the change was to clarify the costs of research and the respective responsibilities of the Councils and the HEIs for supporting Council-sponsored research.

AFRC continues to administer two charitable funds that promote international exchange of scientists. The Wain Fund provides grants for members of staff of UK universities to work overseas, and Fellowships for study abroad by academic staff of universities, including those who have recently completed postgraduate training and expect to enter a research career. Income from the fund for 1991/92 amounted to £35,000. Under this fund visits have been made to Australia, France, Hong Kong, USA and Spain.

The Underwood Fund provides grants for distinguished overseas scientists to visit the UK and undertake research. This has supported visits of scientists from Greece, China, USA, Canada, Australia, Bulgaria and South Africa. Income from the fund for 1991/92 was £51,000.

Expenditure on research grants and research training 1991/92

	£M
Responsive mode	*9.88*
Linked	*3.00*
Cooperative	*0.22*
Centre for Genome Research	*1.23*
Special Initiatives (e.g. Plant Molecular Biology)	*2.79*
Research Training/Fellowships	*2.26*
Total	**19.38**

INTERNATIONAL REPORT

AFRC has continued to use several complementary approaches to strengthen its established international links, and to seek opportunities for new collaborative research initiatives worldwide. These pursue the Council's published objectives on international collaboration that include promoting AFRS research and extending its sphere of influence in policy and programme formulation in Europe and beyond, and effecting closer links with developing countries. Some examples of the approaches used, and particular achievements of 1991-92, are given below.

High level meetings of research policymakers, such as the annual meeting of senior staff of AFRC, MAFF, SOAFD, the United States Department of Agriculture, Agriculture Canada, and the Institut National de la Recherche Agronomique, identify issues and scientific priorities of common interest. Those raised at the 1991 and 1992 meetings included: animal welfare, biodiversity, non-food use of crop production, protein biochemistry and sustainable agriculture. Another example is AFRC participation in the Japan/UK talks on Science and Technology Cooperation, the second round of which took place in September 1991, and from which tropical agricultural research and plant molecular biology emerged as topics of mutual interest.

An important development arising from our established bilateral agreements with INRA and DLO has been the establishment of a tripartite initiative involving AFRC and these bodies. Talks have commenced on extending AFRC's programme of bilateral collaborations. Closer links are being sought with Spain and links are under consideration with Portugal and Greece on areas including animal diseases, soil and crop nutrition and tropical agriculture.

The relevance of AFRC's science to tackling long standing problems of agricultural production in developing countries has been addressed in meetings with the ODA and the British Council, and international agencies, including the Consultative Group on International Agricultural Research. AFRC scientists have continued to participate in wide ranging research training activities in many countries of the developing world.

Scientific meetings and workshops provide an opportunity to identify specific projects for collaboration. Possible workshops on genome research, transgenics and animal welfare have been identified following an Anglo-French Cabinet Office/Ministry of Research and Technology Round Table meeting in May 1991. AFRC has led an initiative, on behalf of the UK Research Councils, to increase scientific liaison in the area of biotechnology between the UK and Australia and New Zealand. This has resulted in several fruitful research collaborations, and momentum is being sustained through a programme of exchanges and visits.

AFRC is increasing its participation in the network programmes of the European Science Foundation, and has supported the launch of a new network on whole plant physiology. AFRC institutes are already involved, for example, the AFRC Institute of Arable Crops Research contributes to networks on soil-water processes, and plant-insect interactions.

The Director General, Professor Tom Blundell FRS (second left) visited INRA at Paris and Jouy-en-Josas in September 1991, and is seen here with the former Director General of INRA, M. Hervé Bichat (left) and colleagues.

Joint scientific groups led by paired UK and Dutch coordinators have proved a successful format for collaborative programmes between AFRC and DLO laboratories under the five year Memorandum of Understanding signed in January 1991. The annual review meeting provides an opportunity for joint forward planning and the identification and development of joint bids for EC funding within the Framework Programmes.

EC funded R&D programmes remain a major area of AFRC international collaborations. AFRC scientists participate in 55 programmes, and income to the Council is on course to meet the target of £3M p.a. for 1992/93.

AFRC has been involved in preparation of the Biotechnology programme of the EC's Third Framework Programme. With the then Department of Education and Science, a Seminar was held in March 1992, outlining the scientific and technical objectives of the programme which has three main components: molecular approaches; cellular and organisms approaches; ecology and population biology.

As well as involvement in scientific programmes, AFRC is contributing to development of the Human Capital and Mobility Programme which seeks to increase the quantity and quality of human resources available for research and technological development.

The successful **Joint Fellowships** scheme between AFRC and INRA is being used as a model for development of a similar scheme between AFRC and CEMAGREF.

Researcher-researcher contacts remain a highly important and productive mechanism of collaboration. These may involve individual researchers or teams as in the recent collaboration between a group at IPSR mapping the *Arabidopsis* genome and a USDA funded programme in the USA.

AFRC initiatives have fostered exchanges and visits for AFRC scientists with The Netherlands, Germany, Spain, and Italy. In addition, effort has been directed at seizing the opportunities offered by the political changes in Eastern Europe and the CIS to develop new contacts in these countries, and to provide advice on research management and opportunities for training.

Dr Mike Gasson greets a deputation from the International Life Sciences Institute, Japan who visited the AFRC Institute of Food Research to discuss food biotechnology and diet and health research.

AFRC engineers are collaborating with scientists in Zimbabwe to develop new cultivation and weeding practices to enhance water and soil conservation.

The Chilean Ambassador to the UK visited the AFRC Institute of Arable Crops Research at Long Ashton in November 1991 to discuss their collaborative research programmes.

HUMAN RESOURCES

On 31 March 1992, 2837 staff were employed on permanent appointments in the AFRC institutes and Central Office; 163 posts were vacant. Of the permanent staff, 1500 were in the Science Group, of whom 94% were at graduate or equivalent levels. A further 716 members of staff, mainly scientists, held short-term appointments funded either by the AFRC directly (312) or by industry and other external sources (404). Short-term appointments have been increasing steadily over the last decade as the volume of short-term income has increased and now account for almost one-third of all Science Group posts. This is significantly above the planning target for 1994/95 of 27%. The increase in short-term appointments reflects a parallel increase in the proportion of the AFRC budget devoted to scientific staff. By March 1992, 62% of AFRC staff were in the Science Group, already in excess of the 1994/95 planning target of 61%.

Training

A new training and staff development strategy was implemented in March 1992, covering initial induction and job-related training, development training (both management and operational), and skills training. New arrangements for monitoring the adequacy and effectiveness of training provision have also been introduced. The new strategy aims to link training provision more consistently and directly with the skills and competencies required at different levels. AFRC took part in a project led by the Office of the Minister for the Civil Service to identify key competencies for scientific management. This will lead to significant changes in the style and content of management training in 1993.

Performance management

The AFRS staff reporting and appraisal system has been revised and restyled as Performance and Personal Development Review. The new system focuses more sharply on employee training and personal development, and the enhanced management effectiveness that can be derived from setting and monitoring performance standards against clear objectives. The training needs element of the PPDR process will link directly to the new training strategy.

Employee relations

AFRC enjoys constructive and positive relationships with the trade unions at both central and institute levels.

New arrangements for negotiation and consultation were agreed and established at the end of March 1992, reflecting the steady trend of delegation to institutes of financial management and personnel responsibilities. At the centre, a new Joint Negotiating and Consultative Committee has replaced the Whitley Council, and Institute NCCs are being established to handle local personnel and employee relations matters.

An Annual Review Meeting, at which the Director General presents the AFRC Corporate Plan and reviews developments during the previous year, replaces the AGM of the Whitley.

Equal opportunities

The AFRS Equal Opportunities Policy Statement has been revised as an action document with measurable targets in all important areas. Significant progress was made towards the policy objectives during 1991/92.

Detailed procedures and policy statements have been drawn up for dealing with cases of sexual and racial harassment, extending employment opportunities for people with disabilities, and promoting flexible

The nursery at the AFRC Institute of Animal Physiology and Genetics Research, Cambridge, provides a stimulating and safe environment for children of staff.

Sixth formers participating in a Conference/Workshop organised by AFRC, the National Centre for Biotechnology Education and the Natural History Museum - part of AFRC's new initiatives on liaison with schools.

AFRC's building programme is providing congenial and well equipped laboratories - shown here is a laboratory in the new block at the AFRC Institute of Grassland and Environmental Research, Aberystwyth.

working patterns and child-care facilities to allow staff to combine more easily domestic and work responsibilities. New recruitment application forms have been introduced to minimise potentially discriminatory elements, and ethnic and gender monitoring of recruitment and employment has begun.

A policy of out-reach to prospective employees with disabilities is being implemented with help from the Disabled Graduates Careers Information Service.

Health and Safety

AFRC places a very high priority on ensuring the health and safety of its employees. The Health and Safety Adviser undertakes annual inspections of all sites and reports to Directors and the Management Committee on findings. A joint committee on health and safety brings management and trade union representatives together regularly. During 1991, a new Health and Safety policy statement was agreed and copies circulated to all sites. Increased effort was devoted to health education policies for AFRS staff, addressing important issues such as AIDS, cervical cancer, smoking and heart disease. AFRC's "Look After Your Heart" programme has been taken forward through institute groups coordinated by the Health and Safety Adviser.

Pay and grading

Treasury proposals to modify the long-term pay agreements for the Civil Service to introduce a greater element of performance related pay, and to allow a greater degree of delegation on pay and grading matters to departments, agencies and non-departmental public bodies, have led to a preliminary investigation of the implications for the AFRS of pay delegation.

Organisation

The Council's restructuring programme launched in 1985/6 has continued to run to schedule. The Hurley and Shinfield sites of the AFRC Institute of Grassland and Environmental Research closed on 31 March 1992 and the new laboratories at North Wyke and Aberystwyth were taken over on 16 January 1992 and 12 March 1992 respectively. The new Reading Laboratory of the AFRC Institute of Food Research was taken over on 1 March 1992, replacing the former premises at Shinfield.

HONOURS AND AWARDS

BIRTHDAY HONOURS

OBE: Mr J M Y Dickens, former AFRC Chief Personnel Officer, Central Office.

BEM: Mrs M I Fearn, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station.

NEW YEAR HONOURS

OBE: Dr K J Brent, AFRC Institute of Arable Crops Research, Long Ashton Research Station.

MBE: Miss Z A M MacDougall, AFRC Institute of Animal Physiology and Genetics Research.

OTHER DISTINCTIONS

Dr T M Addiscott, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, was awarded the 1991 RASE Research Medal.

Professor G Bulfield, AFRC Institute of Animal Physiology and Genetics Research, Edinburgh Research Station, has been elected a Fellow of the Royal Society of Edinburgh.

Dr B A Law, AFRC Institute of Food Research, Reading Laboratory, has been appointed Honorary Professor by the University of Wales Academic Board.

Dr I Morrison, AFRC Institute for Animal Health, Compton Laboratory, was awarded the Wellcome Trust Medal for Veterinary Research.

Dr T Thomas, AFRC Institute of Arable Crops Research, Broom's Barn Experimental Station, has been appointed Visiting Professor in Crop Sciences at the Department of Plant Biology and Biochemistry, Wye College, University of London.

Dr R J Wilkins, AFRC Institute of Grassland and Environmental Research, North Wyke Research Station, has been appointed Visiting Professor in the Department of Agriculture of the University of Reading.

AFRC SENIOR STAFF

Professor T L Blundell FRS
Deputy Chairman and Director General

Dr B G Jamieson
Director of Administration

Dr A V Harrison
Head of Policy Division

Mr R J Price
Chief Personnel Officer

Mr S H Visscher
Chief Finance Officer

Dr J N Wingfield
Head of Science Division

SENIOR STAFF CHANGES

AFRC Silsoe Research Institute

Dr P V Biscoe was appointed Deputy Director and Director of Business Development Division with effect from 22 April 1991.

AFRC Institute of Food Research

Dr F L Davies, Scientific Assistant to the Director, was appointed Acting Head of Norwich Laboratory with effect from 24 December 1991 following the resignation of Professor P Richmond.

AFRC Institute for Animal Health

Dr A I Donaldson, Head of Pirbright Laboratory, was promoted to Grade 5.

INDIVIDUAL MERIT PROMOTION

The following members of AFRC staff were awarded Individual Merit Promotion with effect from 1 July 1991:

Grade 4:

Dr M J Berridge FRS, AFRC Institute of Animal Physiology and Genetics Research, Laboratory of Molecular Signalling.

Grade 5:

Dr R M Moor, AFRC Institute of Animal Physiology and Genetics Research, Cambridge Research Station.

Grade 6:

Dr T M Addiscott, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station.

Dr J A Bailey, AFRC Institute of Arable Crops Research, Long Ashton Research Station.

Dr P W Barlow, AFRC Institute of Arable Crops Research, Long Ashton Research Station.

Dr M J Bibb, AFRC Institute of Plant Science Research, John Innes Centre.

Dr N J Brewin, AFRC Institute of Plant Science Research, John Innes Centre.

Dr M D Collins, AFRC Institute of Food Research, Reading Laboratory.

Dr M J Dauncey, AFRC Institute of Animal Physiology and Genetics Research, Cambridge Research Station.

Dr M R A Morgan, AFRC Institute of Food Research, Norwich Laboratory.

Dr R W Payne, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station.

Dr R Thompson, AFRC Institute of Animal Physiology and Genetics Research, Edinburgh Research Station.

STRATEGY BOARD at 31 March 1992

Chairman
Professor T L Blundell FRS
Deputy Chairman and Director General, AFRC

Members
Professor R B Heap FRS
(Deputy Chairman)
Director of Animal Physiology and Genetics Research

Professor D Boulter CBE
University of Durham

Professor F J Bourne
Director of Animal Health Research

Professor E C D Cocking FRS
Chairman, AFRC Plants and Environment Research Committee

Professor R B Flavell
Chairman, IPSR Management Committee

Professor D L Georgala CBE
Director of Food Research

Professor R M Hicks OBE
Chairman, AFRC Food Research Committee

Dr B G Jamieson
Director of Administration, AFRC

Professor J R Krebs FRS
Chairman, AFRC Animals Research Committee

Professor B J Legg
Director of Engineering Research

Professor T Lewis CBE
Director of Arable Crops Research

Professor J L Stoddart
Director of Grassland and Environmental Research

Professor R Whittenbury
University of Warwick

Assessor
Mr K Moore
SOAFD

THINK-TANK at 31 March 1992

Chairman
Professor T L Blundell FRS
Deputy Chairman and Director General, AFRC

Members
Professor D Boulter CBE
University of Durham

Dr A V Harrison
Head of Policy Division, AFRC Central Office

Professor R B Heap FRS
Director of Animal Physiology & Genetics Research and Director of Science

Professor J R Krebs FRS
University of Oxford

Professor R Whittenbury
University of Warwick

Dr J N Wingfield
Head of Science Division, AFRC Central Office

Secretary
Dr C M Miles
AFRC Central Office

MANAGEMENT COMMITTEE at 31 March 1992

Chairman
Dr B G Jamieson
Director of Administration, AFRC

Members
Mr W Barnes
Secretary, AFRC Institute of Arable Crops Research

Mr D Christie
SOAFD

Professor D R Davies
AFRC Institute of Plant Science Research

Miss C C Dooley
Secretary, AFRC Institute of Food Research

Mr T G Heller
Secretary, Horticulture Research International

Mr R J Price
Chief Personnel Officer, AFRC

Mr P Shaw MBE
Secretary, AFRC Institute of Animal Physiology and Genetics Research

Mr P Swinburne
Secretary, AFRC Institute of Grassland and Environmental Research

Mr D Temperley
Secretary, AFRC Silsoe Research Institute

Mr S H Visscher
Chief Finance Officer, AFRC

Professor R J Wilkins
AFRC Institute of Grassland and Environmental Research

Ms C Yeomans
Head of Administration, AFRC Institute of Plant Science Research

COUNCIL DEVELOPMENT COMMITTEE at 31 March 1992

Chairman
Mr D F R George OBE
Dyfed Seeds

Members
Professor T L Blundell FRS
Deputy Chairman and Director General, AFRC

Professor F J Bourne
Director of Animal Health Research

Professor J M M Cunningham CBE
Formerly West of Scotland College of Agriculture

Mr A H Duberley
Chairman, Finance & General Purpose Committee Country Landowners Association

Dr B G Jamieson
Director of Administration, AFRC

Mr P Powis
Adviser, Herring Baker Harris

Mr G T Pryce
Chairman, Horticulture Research International and Solway Foods Ltd

Mr B A Staples
Mr G C Clark wef 1 May 1992
Head of Buildings and Supplies Branch, AFRC Central Office

Professor J L Stoddart
Director of Grassland and Environmental Research

Mr S H Visscher
Chief Finance Officer, AFRC

Dr J N Wingfield
Head of Science Division, AFRC Central Office

MEMBERSHIP OF THE RESEARCH COMMITTEES at 31 March 1992

ANIMALS RESEARCH COMMITTEE

Chairman
Professor J R Krebs FRS
University of Oxford

Members
Professor I D Aitken
Director, Moredun Research Institute

Professor F J Bourne
Director of Animal Health Research

Dr M J Evans
University of Cambridge

Professor N T Gorman
University of Glasgow

Professor R B Heap FRS
Director of Animal Physiology and Genetics Research

Dr D McE Jenkinson
SOAFD

Dr E B Keverne
University of Cambridge

Professor B J Legg
Director of Engineering Research

Professor M Peaker
Director, Hannah Research Institute

Professor B T Pickering
University of Bristol

Professor R J Roberts
University of Stirling

Dr D W F Shannon
Chief Scientist, Agriculture and Horticulture, MAFF

Professor H Smith FRS
University of Birmingham

Professor J L Stoddart
Director of Grassland and Environmental Research

Mr S P Vranch
Celltech Group plc

Professor D Wakelin
University of Nottingham

Dr M Wallis
University of Sussex

Dr J N Wingfield
Head of Science Division, AFRC Central Office

Assessor
Dr M Kemp
MRC

FOOD RESEARCH COMMITTEE

Chairman
Professor R M Hicks OBE
United Biscuits (UK) Ltd

Members
Professor J P Arbuthnott
University of Strathclyde

Dr J E Blundell
University of Leeds

Professor H Dalton
University of Warwick

Professor G G Dodson
University of York

Professor D L Georgala CBE
Director of Food Research

Mr G E G Harvey
Marks and Spencer plc

Professor W P T James
Director, Rowett Research Institute

Dr D McE Jenkinson
SOAFD

Professor B J Legg
Director of Engineering Research

Professor P J Lillford
Unilever Research

Dr D G Lindsay
MAFF

Professor C Ratledge
University of Hull

Professor D A Ritchie
University of Liverpool

Professor S B Ross-Murphy
Kings College London

Dr J N Wingfield
Head of Science Division, AFRC Central Office

Assessor
Dr S Dyer
MRC

PLANTS AND ENVIRONMENT RESEARCH COMMITTEE

Chairman

Professor E C D Cocking FRS
University of Nottingham

Members

Professor D Boulter CBE
University of Durham

Professor J A Callow
University of Birmingham

Professor R B Flavell
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ACRONYMS

ABA	Abscisic acid
ABC	ATP-binding cassette
ADAS	Agricultural Development and Advisory Service
AFRC	Agricultural and Food Research Council
AFRS	Agricultural and Food Research Service
ATP	Adenosine triphosphate
BTG	British Technology Group
CEC	Commission of the European Communities
CEMAGREF	Centre National du Machinisme Agricole du Génie Rural des Eaux et des Forêts
CFD	Computational fluid dynamics
CFTR	Cystic fibrosis transmembrane regulator
CIS	Commonwealth of Independent States
DANI	Department of Agriculture for Northern Ireland
DES*	Department of Education and Science
DFE	Department for Education
DLO	Dienst Landbouwkundig Onderzoek
DNA	Deoxyribonucleic acid
DTI	Department of Trade and Industry
EC	European Community
ECLAIR	European Collaborative Linkage of Agriculture and Industry through Research
ER	Endoplasmic reticulum
ESRC	Economic and Social Research Council
EWEES	European Waste Engineering Expert System
FAS	Fatty acid synthase
FMDV	Foot-and-mouth disease virus
HEI	Higher Education Institution
H-GCA	Home-grown Cereals Authority
HRI	Horticulture Research International
INRA	Institut National de la Recherche Agronomique
IRES	Internal ribosome entry sites
IT	Information Technology
JII	John Innes Institute
MAFF	Ministry of Agriculture, Fisheries and Food
MHC	Major Histocompatibility Complex
MRC	Medical Research Council
mRNA	Messenger ribonucleic acid
NERC	Natural Environment Research Council
NMR	Nuclear magnetic resonance
NRDC	National Research Development Corporation
ODA	Overseas Development Administration
OST	Office of Science and Technology
QTL	Quantitative trait loci
RNA	Ribonucleic acid
rRNA	Ribosomal ribonucleic acid
RSV	Respiratory syncytial virus
SBE	Starch branching enzyme
SERC	Science and Engineering Research Council
SOAFD	Scottish Office Agriculture and Fisheries Department
USDA	United States Department of Agriculture
WEES	Waste Engineering Expert System

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